TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

No. 82

FAILURE OF BRASS. 1.—MICROSTRUCTURE AND INITIAL STRESSES IN WROUGHT BRASSES OF THE TYPE 60 PER CENT COPPER AND 40 PER CENT ZINC

BY

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and

R. W. WOODWARD, Laboratory Assistant

Bureau of Standards

Specimen No. 8   Specimen No. 161

FIG. 1.—*Season cracked brass rod*

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1. INTRODUCTION

"Can a brass or bronze of high tensile strength be reliably produced which can be used safely for important permanent structures in such parts as bolts and other rolled, drawn, extruded, or forged shapes?" Thus has a well-known engineer recently expressed what may be regarded as the fundamental question which has arisen, as a consequence of the modern tendency among engineers and constructors to substitute such materials for steel, because of their superior resistance to corrosion, and of the recent failure of large amounts of brass used for structural purposes. It is evident that the greater incorrodibility of these copper alloys is of no practical value if the alloys are not at the same time mechanically stable and with well-defined behavior toward service loads and stresses, such that from physical tests their reliability in service may be definitely predicted.

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The recent experience of a number of users of brass for structural purposes has indicated that, in this sense at least, brass is not as reliable as steel; the results of the ordinary physical tests of brass are not always sufficient to enable the engineer to form a definite opinion concerning the serviceability of the material. Properties and characteristics other than those determined in the tensile and hardness tests must be considered in using brass for structural purposes; the relation of certain of these to the occurrence of failures of these materials has been studied in the course of tests and investigation of the last two years.

1. SOME EXPERIENCES WITH BRASS FAILURES

This work was taken up in connection with tests, made for the New York Board of Water Supply, of failed brass bolts, which had been in service in the construction of the new Catskill Aqueduct, which is to supply water to the city from the watersheds of the Catskill Mountains.

In view of the fact that most of the equipment and materials used in this construction would be subjected to the corroding action of both water and the atmosphere, a substitute was sought for steel, which would ordinarily be used, and it was considered possible to find a brass which would have mechanical properties comparable with those of steel and yet be practically incorrodible. As such a substitute so-called manganese "bronze" was chosen and also other similar brasses, which all have approximately the same composition, namely,

	Per cent
Copper.	58.0 to 62.0
Zinc.	36.0 to 40.0
Tin.	.5 to 1.5
Iron.	.0 to 1.0
Manganese.	.0 to .2

These materials, as wrought, have ultimate tensile strengths ranging from 50 000 to 75 000 pounds per square inch and seem admirably adapted for this purpose, so much so that some 3 000 000 pounds of these materials, in the form of castings, wrought rods, and tubing, have been installed on the aqueduct. Serious difficulties have, however, been encountered in their use and many failures have occurred, some under moderate or large service loads and some, on the other hand, merely during shipment and storage. "Large[1] numbers of brass bolts have been found cracked

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[1] A fuller account of the experience of the New York Board of Water Supply with these brasses will be found in a paper read in 1914 by A. D. Flinn before the municipal engineers of New York City, entitled "Brass in Engineering Construction," and from which quotation is made here and more fully on page 5.

and broken in their packing cases after storage through a winter, but having never been stressed; others never exposed to low temperatures and never stressed have been found in similar condition. These bolts ranged from one-half to $2\frac{1}{4}$ inches in diameter. Similarly, flat bars, rolled plates, and long rods supporting only their own weight have been found cracked or severed after a lapse of a few or many months. Flanged one-fourth-inch plates riveted together, after careful inspection being in apparently good condition, were found some months later to have incipient and well-developed cracks, with many rivets cracked or yielding to relatively light blows from a hand hammer. Many upset bolt-heads have come off. Hundreds of bolts have broken under tension after short or long intervals. No brand or make of brass or bronze has wholly escaped. Manganese bronze, naval brass (including a well-known bronze and its imitation), and Muntz metal, from all the manufacturers who have furnished any considerable quantity, all have failed. Hitherto castings and large forgings have been exempt, or at least failures in them have not been discovered except in a few cast bolts and nuts" (and it should be added in the case of burned-in castings at or near the burned-in areas).

The New York Board of Water Supply is not alone in its experience with brass failures, although the amounts of material involved in its case lend it prominence. The engineer's department of the city of Minneapolis have lately—1914—experienced similar difficulties with naval brass strainer plates and bolts installed in their new filter plant, and some interesting instances of failures of this type occurring in manganese-bronze bolts used in the construction work of the Panama Canal have come to our attention.

Specimens from these three parties form a large part of the material investigated, and for this reason a more detailed account of the difficulties encountered with these materials by the New York Board of Water Supply, the engineer's department of the city of Minneapolis, and the engineers of the Panama Canal is given below in the form of quotation from published article or correspondence.

QUOTATION FROM MR. FLINN'S PAPER (LOC. CIT.) CONCERNING BRASS FAILURES ON CATSKILL AQUEDUCT

Claims of the brass or bronze makers, backed up by tests and experience, led the engineers of the Catskill Aqueduct, after careful investigation, to adopt some of these copper-zinc alloys for extensive use where their noncorrodibility and other good qualities claimed for them made them especially suitable. It is safe to say that on

no other single engineering enterprise have such large quantities been used, the total being nearly 3 000 000 pounds. Of castings, ranging from a fraction of a pound to 22 000 pounds each, there have been a total in excess of 2 000 000 pounds; of forgings, a large proportion of the remainder, varying from small bolts to sluice-gate stems about 6 inches in diameter, 31 feet long, weighing 3 200 pounds apiece. Plates, rods, and shapes make up the balance. Manganese bronze constitutes a very large proportion of the total; "naval brass," including Tobin bronze, was used in large amounts; various common brasses and special compositions make up the relatively small remaining quantity. * * *.

It is not with these large brass castings, which are so important, nor with the large forged stems of sluice gates and valves, nor with the smaller castings, excepting a few cast bolts, that the interesting and trying subsequent experiences have been had. Designing, casting, forging, machining, testing, and installing these large objects have involved the solving of many interesting problems, but the unexpected metallurgical developments have occurred in the smaller objects, such as bolts, ladders, and pipes, which when they go wrong have capacities for trouble quite disproportionate to their sizes.

These numerous and various brass articles have been made by a number of manufacturers scattered through New England, New York, Pennsylvania, and New Jersey. Their methods and equipment were of their own selection with very few exceptions, and apparently were developed by experience. Some of these manufacturers of brass or bronze have had experience equaling or exceeding, in number of years, the period of manufacture of modern steels. Consequently the troubles which have occurred so extensively on the Catskill Aqueduct have been all the more astonishing, and lack of information concerning such troubles the more incredible. Not alone the Board of Water Supply, but other users have also had trouble of one kind or another, but knowledge of such trouble has come to hand only within relatively recent time. Just when, as to date or in the state of development of brass manufacture, these troubles began or how extensive they have been has not yet been learned. Possibly they might still be considered occasional or accidental, but for the large and concentrated use of these alloys on the Catskill Aqueduct under such supervision as led to the detection of the difficulties and a thorough investigation of their causes, together with their bearing upon the use of such alloys in engineering construction. * * *

No suspicions of definite troubles were developed until the fall of 1913, when numerous bolts and rods were found cracked. The number and character of the failures detected strongly suggested that they were more than accidental or sporadic.

Failures were the more disturbing because the specifications had been drawn carefully, in the light of information then in hand, and practically all the metal accepted had been subjected to careful inspection, including the standard physical tests and chemical analyses. Much of the metal accepted had shown physical qualities in generous excess of the specified requirements. It is quite unthinkable that the manufacturers were not honestly endeavoring to fulfill the specifications and furnish satisfactory materials, although they may have been misguided as to means and methods in some instances and somewhat influenced by commercial considerations. What, then, was the root of the matter? It is the answer to this question which is still sought. * * *

The results of a number of representative inspection tests are given, as examples. * * *

Typical results of physical tests of brasses used on the Catskill Aqueduct

Yield, pounds per square inch	Ultimate strength, pounds per square inch	Elongation, per cent	Reduction, per cent	Fracture
Forgings:				
36 500..	73 150	41. 5	46. 8	Irregular.
37 500..	75 750	35. 5	43. 9	Do.
38 250..	76 900	35. 5	46. 8	Do.
52 500..	77 100	31. 0	....	Irregular, silky.
49 300..	76 150	33. 5	....	Silky cup.
50 000..	75 350	31. 0	....	Irregular, silky.
43 500..	70 000	34. 0	47. 0	Irregular.
36 000..	67 500	40. 5	43. 5	Do.

But little trouble has been experienced with the pipes furnished by reputable manufacturers in recent years. A few small pieces have failed on the Catskill Aqueduct. There is but small excuse for supplying other than dependable brass pipe nowadays, as correct methods of manufacture are well known in the trade.

Defects in large plates, in bolts, rods, side bars, and rungs of ladders and in similar objects constituted the most important lots of failures on the aqueduct. Many of these articles had not yet been installed, but had been in storage in some instances for many months. These defective pieces all had cracks, usually circumferential, part way or all the way around. Some cracks were very fine and only superficial; others gaped open and penetrated the metal deeply. In some cases the whole or nearly the whole cross section was affected in bolts from one-half to 2¼ inches in diameter; some were found severed and others broke with a light blow or pull. Specimens which on first examinatian seemed free from this cracking developed it later; two or three years have passed in some cases before the defects developed so as to be detected. Investigation disclosed the fact that similar defects had been observed by others in a variety of metals, but chiefly in drawn or otherwise cold-worked brasses. Although not then satisfactorily explained, this trouble was known among brass men as "season cracking." * * *

After the discovery of the extensive season cracking and a partial investigation of its causes, it was decided to use plain extruded or hot-rolled rods wherever practicable and to anneal all material which had been drawn or rolled cold. It was hoped that by these methods of manufacture further trouble of this kind would be avoided, but unfortunately this has not proved to be the case. Plain extruded, hot-forged, and annealed brass rods, supposedly free from initial stress, have also failed in disturbingly large quantities. * * *

Designers have been misled to some degree by the representations of the manufacturers that certain bronzes (brasses) possessed great strength and other excellent qualities, and in some cases would perform practically the same duty as steel or a little more. Seemingly both maker and user have misinterpreted the results of the usual standard laboratory tests from lack of knowledge of characteristics of the copper alloys not revealed by such tests. Experience on the Catskill Aqueduct indicates that the bronzes (brasses) as supplied under contract, with careful inspection following the established methods, would not perform the expected duty. Indeed, as these investigations have proceeded it has become evident that the engineer's present necessity is not merely an explanation of certain failures of brass, but a fundamental knowledge of the physical characters and capacities of this group of alloys—knowledge which will be a safe and dependable guide in their manufacture, inspection, and use.

To summarize the Catskill Aqueduct experiences: Large numbers of brass bolts have been found cracked and broken in their packing cases after storage through a winter, but having never been stressed; others never exposed to low temperatures and never stressed have been found in similar condition. These bolts ranged from one-half inch to 2¼ inches in diameter. Similarly flat bars, rolled plates, and long rods supporting only their own weight have been found cracked or severed after a lapse of a few or many months. Flanged one-quarter-inch plates riveted together, after careful inspection being in apparently good condition, were found some months later to have incipient and well-developed cracks, with many rivets cracked or yielding to relatively light blows from a hand hammer. Many upset boltheads have come off. Hundreds of bolts have broken under tension after short or long intervals. The failures have been so numerous and important as to have caused the gravest apprehension and led to the substituting of steel for brass in many cases in spite of the recognized disadvantage of steel as to corrosion which the engineers had sought earnestly to avoid. No brand or make of brass or bronze has wholly escaped. Manganese bronze, naval brass (including a well-known bronze and its imitation), and Muntz metal, from *all* the manufacturers who have furnished any considerable quantity, *all* have failed. Hitherto castings and large forgings have been exempt, or at least failures in them have not been discovered, except in a few cast bolts and nuts.

For the designing and constructing civil and mechanical engineers, the following questions should be satisfactorily answered if they are to continue the use of these brasses or bronzes for important purposes:

Can a brass or bronze of high tensile strength be reliably produced which can be used safely for important permanent structures in such parts as bolts and other rolled, drawn, extruded, or forged shapes?

What should be the specifications for such brasses or bronzes?

What inspection methods and tests should be used?

By what tests can the tendency to subsequent failure be detected at any time after manufacture?

What working stresses may be used safely for these various alloys?

Will these brasses or bronzes deteriorate by reason of constantly applied or frequently repeated stress; *i. e.*, will they fail from fatigue?

QUOTATION FROM LETTER REPORT BY THE CITY ENGINEER OF THE CITY OF MINNEAPOLIS CONCERNING DIFFICULTIES WITH BRASS STRAINER PLATES AND BOLTS

Early in the spring of 1912 the city of Minneapolis advertised for bids on the entire strainer system for their new filter plant then under construction. Among the various items comprising the strainer system were 1224 middle strainer plates, 2448 side strainer plates, 3672 one-fourth-inch brass bolts, 12 240 one-fourth-inch brass U-bolts and 12 240 one-half-inch anchor rods, all as per drawings herein shown and according to the specifications noted below. [See Appendix.] * * *

During the fall and winter of 1912 the entire lot of plates and bolts were placed in their respective places in the various filter boxes and early in January, 1913, 6 of the 12 filter units were placed in operation.

No trouble whatsoever was experienced for the first 30 or 40 days of operation. After the above period, however, the center plates began to break longitudinally through the center, and soon after a number of the side plates cracked crosswise at the end nearest the center of the filter box. At first no great attention was paid to the breakage, but before the summer was very far advanced the breaking of plates was an everyday occurrence and became so very bad that it was necessary to remove the entire lot from each filter box (one at a time) and replace the broken plates with new hard brass plates and reinforce all the remaining center Tobin bronze plates with a strip of one-eighth-inch sheet brass riveted longitudinally along the center of the plate. This reinforcement improved matters somewhat but did not obviate the breakage entirely.

Tensile and bending tests were made on pieces of metal cut from the broken plates, with results that were very satisfactory. * * *

A peculiar thing about the whole affair was that very few of the side plates broke, and when they did break the fracture was at right angles to that of the center plates. After a careful study of the matter, it was decided that the design, as used, had many faults, and that by redesigning the plates and their connections, making the plates heavier, decreasing the friction through the openings and reinforcing by ribs against the greatest pressure, all breakage would be overcome. * * *

A design for improving the filter strainer system as per accompanying plans was immediately prepared with the specifications noted below [see Appendix] to govern, all unit stresses being the minimum stress as set forth in the pamphlet hereinbefore mentioned. * * *

Immediately upon the arrival of the material for the new strainer system one filter box was equipped completely and the wash water turned on for a test before any gravel or sand was placed in the filter box. Unusual agitation of the water was noticed at a number of places, which upon investigation proved to be caused by the breaking of a number of the anchor bolts, as shown by samples in the city engineer's office. These broken bolts were removed and replaced by new ones, again tested, found all right, and the gravel and sand added immediately. After operating the filter for about a week, the filter again showed breaks. The sand and gravel were removed and the entire lot of center plates with their anchor bolts taken out. There was scarcely a plate that did not have one or more broken or cracked anchor bolts, and in some cases the plates themselves were cracked. Believing that the above breakage of bolts was due to flaws in the material and that the plates broke on account of too great a pressure concentrated at one point due to the breaking of the bolts, it was decided to replace the bolts by new ones, but before doing so, to test all bolts in tension to a dead load of 800 pounds each, also to test a number of bolts to failure for both tension and cross bending. Accordingly a number of bolts were tested on a testing machine until the hook at the end straightened out, which took place at a load varying from 1420 pounds to 1350 pounds each. In the bending tests all bolts were bent through an angle of 180° flat on themselves without showing fracture on the bent portion. When tested to failure in direct tension, the bolts gave a unit tensile stress varying from 71 000 pounds to 100 000 pounds per square inch. Therefore, it was concluded that the material was probably all right and safe to use after being tested to the 800-pound load. Before placing any tested bolts in the filters, each bolt was examined carefully, some by means of a low-power microscope. No flaws being evident, the bolts and plates were again put in place. Before testing the strainer system, the bolts were gone over carefully and about 10 per cent found to be loose, caused by the cracking or complete failure of the bolt as before noted. All bolts and plates were again removed and a new lot of bolts heated in a furnace to a cherry red, then quenched in lukewarm water, tested to 600 pounds (all that they would stand without straightening out), and put in place. This improved matters a great deal, no failure was noticed in the filter so equipped until about four weeks after it was placed in operation, when a number of the strainer plates were blown completely from their seats and up through the gravel, which proved upon investigation due to the breakage of the anchor bolts as before noted. At this time some of the strainer plates again began to fail, and one plate was found cracked longitudinally through the center before it had even been placed in the filter.

The plates instead of cracking as in the original installation (longitudinally through the center) seemed to crack in every manner possible and followed no definite lines, appearing very similar to the checks in sun-dried lumber. Samples of the broken bolts and plates were sent to the testing laboratory, the contractor, and the manufacturer, but no one seems to be able to explain the cause.

A test, by means of a pressure gage, was made of the maximum water pressure underneath the plates and found to be 7½ pounds per square inch, amounting to a pull of only 270 pounds on each hook bolt, which was far below the original stress of from 600 to 800 pounds to which the bolts were tested before installation.

QUOTATION FROM LETTER REPORT BY THE CHIEF QUARTERMASTER, PANAMA CANAL, CONCERNING THE FAILURE OF MANGANESE-BRONZE BOLTS

About the middle of October last year the operator of the Gatun Hydroelectric Station advised that one of the counterweights of spillway machine No. 13 had dropped into the pit without warning and at a time when the machine had not been operated for some time, the gate being in the closed position at the time of the accident.   *   *   *

Under date of December 17, 1915, the electrical engineer was requested to make a report of his investigations in connection with the breakdown, and a copy of his reply dated December 21, 1915, is attached [immediately following].

I have to report that all four bolts on the west counterweight of Gate 13 at Gatun Spillway broke under the head while the counterweight was at rest with the gate closed. The fracture indicates that the metal (manganese bronze) was burned when the heads were upset, as all four bolts failed within an inch of the head.

Test pieces were cut as near the fracture as possible and tested in the Riehle testing machine at Balboa shops, with the following results:

Sample	Diameter	Area in square inches	Elastic limit per square inch in pounds	Ultimate stress per square inch in pounds	Elongation, per cent in 2 inches	Reduction of area, per cent
No. 1	½ inch..	0. 196	....	73 750	26. 0	39. 8
No. 2	½ inch..	. 196	49 650	74 800	28. 0	42. 9
No. 3	½ inch..	. 196	....	72 450	31. 5	43. 4
No. 4	½ inch..	. 196	47 750	74 650	28. 0	42. 4

The physical test requirements of the specifications in Circular No. 661, under which these bolts were purchased, are as follows:

Ultimate stress per square inch in pounds............. 70 000
Elastic limit per square inch in pounds............... 40 000
Elongation, per cent.................................   25
Reduction of area, per cent..........................   25

An examination of these bolts shows plainly, aside from the fracture, that the metal had been burned, as stated, and in order to ascertain whether or not similar results were to be expected in other bolts in the remaining counterweights we removed two bolts from the adjacent counterweight on this gate. These bolts indicated no overheating or burning, and tests were made to determine the physical strength of the bolts under the head. They were tested in the same machine as the samples above referred to and were subjected to a tension of 100 000 pounds, with no signs of failure. The bolts were then turned down to a diameter of 1.125 inches and test again made, with the following results:

Sample	Ultimate stress per square inch in pounds	Area in square inches	Remarks
No. 1	61 400	0. 994	Head of bolt pulled off.
No. 2	63 900	. 994	Do.

This result indicates a rather low ultimate stress for first-class manganese bronze, which should be around 95 000 to 100 000 pounds per square inch, but the fracture indicates good metal.

Each spillway counterweight consists of 56 cast-iron blocks weighing 750 pounds each and a base plate weighing 3700 pounds, making the total weight 45 700 pounds. This weight is supported from the counterweight yoke with four manganese bronze bolts, each 1¾ inches in diameter. Assuming that the load is equally distributed between the four bolts, there is then a load of 11 425 pounds. The bolts being 1¾ inches in diameter have an area of 2.405 square inches, which gives a load of 4750 pounds per square inch, and from the results of the second test gives a factor of safety of approximately 15.

About the middle of November, 1915, and shortly after the accident to the Gatun Spillway counterweight bolts, the superintendent of the Gatun Locks advised that one of the counterweights of the guard-valve machines at that point had dropped into its pit without any resulting damage to any of the equipment, however. * * *

The superintendent of the Pacific Locks has reported, under date of December 30, 1915, as follows:

I have to advise that this morning a second broken bolt was found in the spillway counterweights. The pieces have not yet been recovered for examination, but the location of the break is similar to that found yesterday.

The heads of these bolts were inspected as far as possible visually about two months ago. I also had visual inspection of the rest of the bolts made this morning, and as far as could be seen the rest of the bolts were still intact. * * *

The head from the bolt found broken yesterday is being forwarded to you under separate cover. You will note that the fracture is quite crystalline, and that there was practically no reduction in area. There appears to have been practically no elongation. The dark stain in the fracture I believe comes from the iron, and it would indicate that the metal apparently cracked progressively until the area became so reduced that finally rupture occurred. * * *

One or two small surface cracks are visible with the aid of a small magnifying glass in the body of this bolt. * * *

The superintendent of the Atlantic Locks reported as follows:

1. With reference to your letter of December 17, 1915, I have to report that on October 21 the U bolt supporting the counterweight on guard valve No. 226 failed, dropping the counterweight into its well.

2. The U bolt which is forwarded separately for test, if desired, was broken in two places, namely, at top of one of the nuts and at the shoulder of the U opposite to first break.

3. As the roller trains were connected through separate chains to the main counterweight, the ¾-inch connecting shackles failed when the counterweight dropped. No other parts were damaged.

4. The guard valves were not in operation when failure occurred, the last operation being two days previous to the accident, when they were given rather heavy service in an attempt to cut down the leakage through them.

5. The total weight of the counterweight is 28 580 pounds, which under normal condition would make the load on each leg of the U bolt 14 290 pounds. Indications are that the weight was not equally divided, as the legs now differ in length by approximately 1 inch, and it is not believed the distortion produced by the accident could have amounted to so much. Assuming all the weight to have been on one leg the total stress would have been 28 880, or 17 610 pounds per square inch for the area at the shoulder break of 1.623 square inches. The I. C. C. specifications given in Cir. 636 for rolled bronze require an ultimate strength of 65 000 pounds per square inch and elastic limit of one-half this.

6. The fracture at the nut shows a crystalline structure with an indicated fibrous structure at right angles to the length of the bolt.

7. The fracture at the shoulder shows about one-third fibrous and two-thirds crystalline structure. A vertical crack 1 inch long, showing on one side of the bolt, marks the plane between the two areas.

8. The remaining U bolts have been examined and indications are that they are o. k. I recommend no further action be taken.

Although, as will be brought out later, some differentiation in characteristics can be made between these various instances of brass failures, they bear a striking similarity to that type of failure known as "season cracking," connoting the formation of cracks or fissures in wrought-brass articles some time after their manufacture, although the articles had been sound originally and had even passed rigid inspection and test. Examination of such material, in the usual way, will show it to possess desirable physical properties, as indicated by the tensile test, satisfactory chemical analysis, and sound structure, as shown by etching tests and the microscope. Apparently no usual cause can be assigned for the defective nature of this material; these failures will often occur before the application of any appreciable external stress or load. This type of failure is perhaps most common in tubes, but is found also in all types of wrought brass, be they rolled, drawn, stamped, or spun; its seriousness arises from the fact that ordinary tests will not indicate the possibility of its occurrence.

The manufacturer knows this phenomenon most familiarly as "fire cracking," or the cracking of the drawn or cold-worked material upon putting it in the annealing furnace; samples of such "fire-cracked" material are generally not difficult to find in a brass mill.

2. LITERATURE ON "SEASON CRACKING"

The first reference to failures of the type of season cracking is given by Diegel,[2] who describes instances of such failures in brasses and bronzes, and ascribes it to the presence of initial stresses caused by cold working and to the gradual "after flow" of metal, which he claims continues even after the cold working of the metal has ceased. He also finds that the tensile strength and the elastic limit of cold-worked aluminium bronze which had season cracked were greater at the edge than at the center.

In the same year appeared an anonymous article [3] in which the author finds that "season cracks in tubing are the results of taking

[2] Diegel, Nachträgliches Reissen kaltverdichteter Kupferlegierungen, Verh. d. Ver. z. Bef. d. Gewerb., 85, p. 177; 1906.

[3] Anon., Season Cracking in Brass, Brass World, 2, p. 41; 1906.

too heavy 'pinches' in drawing. The specimens experimented upon were some hot and cold rolled 10 per cent aluminium bronze. The results were as follows:

1. The hot-rolled bars did not suffer from season cracks.

2. Although the elastic limit in the cold-drawn bars was greater than in those which had been hot rolled, they showed season cracks after some time.

3. The reason for the formation of season cracks is the lack of uniform density throughout the metal, as the tests indicated that the elastic limit decreased rapidly toward the center.

4. The density varied in the inverse proportion to the cross section. The larger diameters were more apt to crack. The average density of the whole cross section and the elasticity of the metal appeared to have less influence on the formation of cracks than the extreme variation of the density from periphery to center.

5. The formation of longitudinal or cross cracking depended on the methods used for drawing the bars."

Several articles appeared at this time describing instances of season cracking and ascribing it variously to the action of ammonia vapor;[4] to faulty die and punch construction.[5]

An interesting case of the failure by season cracking of brass stirring spindles is described by Desch in the discussion of a paper on this subject by Milton.[6] These spindles were used to stir a liquid at a temperature near its boiling point; those which had not been in service fell to pieces in a short time, whereas those of the same lot which had been so used remained sound, the initial stresses having been sufficiently relieved at the temperature of the boiling liquid.

Sperry[7] maintains that season cracking can be caused by the presence of initial stresses or by the action of mercury or aqueous solutions of its salts, and describes failures of this sort which have occurred in brass prepared by a mercury salt "dip" for gold or silver plating.

The first one to actually measure the initial stresses, about which so much had been said, was Heyn,[8] who developed methods for measuring theses stresses (to be described below) and gave diagrams constructed from such measurements, showing the distri-

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[4] Season Cracking in Brass Sheet, Brass World, 6, p. 269; 1910.

[5] Anon., Effect of Dies on Season Cracking of Drawn Brass, Mechanical Engineer, 27, p. 159; 1911.

[6] Milton, Some Points of Interest Concerning Copper Alloys, Journ. Inst. Metals, 1, p. 57; 1909.

[7] E. S. Sperry, The Season Cracking of Brass and Other Nonferrous Metals and Alloys as Caused by Mercury, Brass World, 8, p. 345; 1912.

[8] A. Martens and E. Heyn, Materialienkunde für den Maschinenbau, IIA; 1912. E. Heyn, Internal Stresses in Cold Wrought Metals, and some Troubles Caused Thereby, Journ. Inst. Met. 12, p. 3; 1914.

bution of the longitudinal or axial stresses in steel and brass rods which had failed. He discussed also the conditions of manufacture under which stresses are produced in worked metals.

Spontaneous or season cracking occurs in such internally stressed objects, according to Heyn, as a result of temperature variations of after flow of the metal and particularly as a result of slight etching of the surface, which diminishes the section of the stressed metal, thereby increasing the stress and causing cracks to appear. He gives the results of some experiments to show that these stresses are removed from brass rods by annealing at temperatures (160° to 300° C), at which no appreciable softening of the material occurs. He also discusses the effect of longitudinal internal stresses on the yield point of a metal, and shows that the apparent elastic limit of metals may be depressed instead of raised by cold work.

Some later measurements of the initial stresses in brass bars were made by Howard.[9]

Further articles [10], [11], [12], [13] appearing about this time discuss the relation of initial stress to failure, and describe experiences with such failures. Von Aken finds in the variation in the microstructure from center to edge of brass rods a sufficient cause for season cracking in these materials and recommends annealing at 1300° F (700° C) as a remedy.

Guillet [14] in a general paper calls attention to the possibility, among others, of season cracking of high zinc brasses being due to the decomposition of the beta phase into the brittle gamma eutectoid.

Finally, Jonson [15] describes the results of some very interesting experiments, showing the effect of combined corrosion and tensile stress on the ductility and strength of brass and bronze alloys. He studied the effect of subjecting brass to combined stress and corrosion with ammonium hydroxide, and draws the following conclusions:

* * * Excessive stress alone does not injure copper alloys, nor does corrosion alone or corrosion accompanied by moderate stress. Corrosion, accompanied by prolonged stress, exceeding 20 000 pounds per square inch, is liable to cause cracking in

[9] J. E. Howard, Internal Strains in Rolled Brass and Bronze Bars, Trans. Amer. Inst. Metals, 7, p. 101; 1913.

[10] Anon., Observations and Notes on the Season Cracking of Brass, Brass World, 9, p. 155; 1913.

[11] A. E. White, An Investigation of Condenser Tubes; 1914.

[12] A. D. Flinn, Brass in Engineering Construction, Eng. Record, 68, p. 527; 1913.

[13] Von Aken, The Cracking of Brasses and Bronzes, Engineering Record, 70, p. 227; 1914.

[14] L. Guillet, Nouvelles Recherches sur les Alliages de Cuivre et de Zinc, Revue de Métallurgie, 11, p. 1094; 1914.

[15] E. Jonson, Failures of Forgible Brass Bars, Trans. Amer. Inst. Metals, 8, p. 135; 1914. The Fatigue of Copper Alloys, Proc. Am. Assn. for Testing Materials, 40, p. 101; 1915.

any of the above-mentioned alloys. We must therefore regard 20 000 pounds per square inch as the practical ultimate strength of copper alloys, and the working stress must be taken as a safe fraction of this ultimate stress.

The following facts seem thus to be established to date:

(1) Season cracking and similar failures occur particularly in brasses of copper content of from 60 to 80 per cent, as well as in other metals and alloys, such as nickel steel and aluminum. W. H. Bassett, in commenting on this point, states that "season cracks have never, in the writer's 25 years' experience with copper-zinc alloys, occurred in such alloys containing more than 80 per cent of copper. They are more apt to occur in alloys containing lower percentages of copper, because the hardening, due to the mechanical working, is more rapid, and the alloys, on account of the influence of zinc and other constituents, have an initial hardness, due to composition."

(2) These failures occur generally only in forged or worked metal,[16] and the cracks are found some time after the articles have passed inspection, both in service, under load, and even before being put into actual service.

(3) The material after the appearance of the season cracks or fractures still possesses good mechanical properties as indicated by the tensile and bending tests, including high elongation and reduction of area. This is significant in view of the fact that the fissures and fractures all occur without appreciable elongation.

Certain factors seem to favor the development of such cracks. These are:

(1) Temperature variations; it seems to be pretty well established that exposure, particularly to low temperatures, may start season cracks.

(2) The action of air, water, and other corrosive agents on the surface of the material.

The general opinion regarding the cause for brass failures of this sort as definitely enunciated by Heyn, although not always so clearly stated by others,[17] is that the primary cause is the presence of initial internal stresses. The presence of such initial stresses has been demonstrated by Heyn and by Howard, and values of these stresses determined in materials which have failed, thus giving confirmation to this explanation.

Guillet expresses the opinion that the formation of the brittle gamma constituent may be in certain cases responsible for such

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[16] Such failures have, however, been noted in "burned-in" and other castings.

[17] The statements that "imperfect die work," "too little annealing," are responsible for this type of failure amount in the last analysis to ascribing it to the presence of internal stresses.

failures; he has in mind either the presence of this constituent as an actual segregate or in apparent beta, the eutectoid of Carpenter. The appearance of such a constituent would embrittle the material and cause it to become less resistant to stress.

From the foregoing it seemed evident that in addition to the ordinary tests of the failed materials in question investigation should be made of the presence in them of initial stresses and, in general, of the relation of magnitude and distribution of internal initial stresses to the occurrence of season cracking and similar failures in brasses.

The following questions may be raised:

(1) What are the characteristics and what the causes of the failures which have occurred?

(2) What is the relation of the initial stresses to the occurrence of failure?

(3) Can a safe limit for these stresses be set for different types of brass, under ordinary service conditions, in which the material is subjected to both corrosion and external stress?

(4) What are the stresses to be found in new material manufactured to meet high specifications?

(5) Can, for a given chemical composition of such material, those limits of mechanical properties be ascertained above which one may not go in manufacturing brass without leaving the metal dangerously internally stressed? It is well understood that, in general, a high tensile strength and elastic limit are imparted to brasses by cold work, which at the same time leaves stresses in the material, so that high ultimate strengths and elastic limits may be obtained at the sacrifice of soundness.

(6) What is the quickest and most convenient method for ascertaining whether a material is internally stressed and of determining the approximate value of these stresses?

In addition, therefore, to the failed and other brass materials secured through the New York Board of Water Supply, the engineer's department of the city of Minneapolis, the Navy Department, and the Panama Canal, various samples of wrought brass were obtained directly from manufacturers, investigation of which might furnish partial answer to questions 4 and 5. These materials are described in detail immediately below.

FIG. 2.—*Season cracked brass*

Specimen No. 125
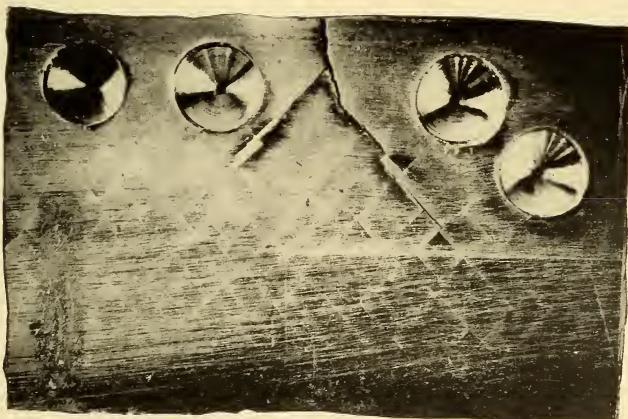
FIG. 3.—*Season cracked ladder side bar*

Specimen No. 211
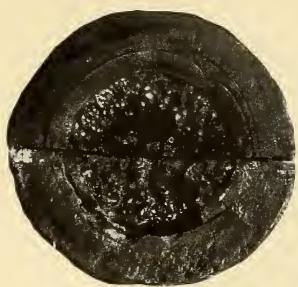
FIG. 4.—*Fracture*

Material 10 × 1

FIG. 5.—*Fracture*

Material 35 × 1


FIG. 6.—*Fracture*

Material 46 × 1

FIG. 8.—*Fracture*

Material 68 × 1

FIG. 7.—*Fracture*

Material 65 × 1

II. INVESTIGATION OF BRASS MATERIALS

In Table 1 is given a description of the various samples that have been investigated of materials which have been in service, together with whatever information is available concerning the service conditions to which they, or the lots of material which they represent, have been subjected. Unfortunately, this information is often very meager; indeed, the lack of such information often makes impossible the deduction of definite conclusions.

In Table 2 is given information concerning the new materials tested.

It will be noticed, in considering the failed materials of Table 1, that several kinds of material are involved, as well as several manufacturers of the same kind of material. The material has all been worked, hot or cold; cast material has seldom been found defective in this manner (with the exception of castings repaired by burning in). The failure by cracking occurred sometimes merely after shipment and storage, and in other cases after having been some weeks or months in service under service stresses of widely different values. These cracks or fractures are in all but a very few cases transverse or perpendicular to the direction of rolling or drawing. Such fissures are shown in Fig. 1. In the case of large lots of strainer plate, the cracks or fissures were generally longitudinal or parallel to the direction of rolling, as shown in Fig. 2, while the fractures in some bolts were conical in shape or cupped, as shown in Fig. 7. The checks in No. 211, Fig. 3, are particularly interesting, reminding one of the Lüder lines.

The fractures were generally of bright granular or crystalline texture (this does not mean the fracture was intercrystalline), but often also of silky texture. Typical fractures are shown in Figs. 4 to 8.

Table 3 gives the results of chemical analyses and physical tests of these failed as well as of other brass specimens tested in connection with this investigation. The tensile tests were made on a specimen machined from the center of the sample, of about 0.5-inch diameter and of 2 or 3 inches gage length.

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TABLE 1
Description of Materials Which Have Been in Service

B. S. No.	Article, material, etc.	Service: Conditions, etc.	Description and extent of failure
M 1-3....	1¼-inch diameter, manganese-bronze bolts, sent in by the B. W. S.[a],[b].	These bolts had never been installed, but had been stored for some time.	Transverse fissures appeared in Nos. 1 and 3 after lying in storage over winter. Longitudinal cracks appeared in No. 2.
M 7-8....	1⅜-inch diameter, manganese-bronze bolts, sent in by the B. W. S.[a],[b].	The bolts were subjected to shipment and storage only.	These bolts showed transverse cracks or fissures.
M 9......	2 by ½ inch flat bar, naval brass, submitted by the B. W. S.[a], manufactured by B.	Shipment and storage..............	Transverse cracks starting at edge.
M 10-14...	¾-inch naval-brass rivets, submitted by the B. W. S.[a]	Forged in place..............	Heads fractured off in case of Nos. 10 and 11; other rivets were sound.
M 20-39...	1⅜-inch diameter, stud bolts of manganese bronze, submitted by the B. W. S.[a] They were forged and machined by manufacturer A[c]; bolts about 6 inches long.[d]	This lot of bolts was used to make up ground-flanged joints of riser valves and were drawn up tightly, probably over the elastic limit. The amount of corrosion had been slight—the surface of the bolts was barely tarnished.	The bolts stood shop test, but after installation approximately 83 per cent failed after some 10 months in service. Nos. 20-29 are samples of bolts which did not fail, whereas Nos. 30-39 are failed bolts. The failures in the latter case were by transverse fracture or fissure at the base of the thread; the fracture was medium crystalline or granular.[e]
M 40-48...	1-inch diameter tap bolts of manganese bronze, submitted by the B. W. S.[a] They were forged and machined by A[c]; bolts about 3 inches long.[d]	This lot of bolts was subjected to same treatment as preceding; that is, probably overstressed. The corrosion had been somewhat more severe—a bronze patina had formed.	The bolts stood shop test, but about 10 months after installation approximately 16 per cent of the bolts were found cracked. Nos. 40-45 did not fail; Nos. 46-48 did fail. Failure was by transverse crack or fracture at base of thread; fracture was medium crystalline.
M 49-68...	1¼-inch diameter, hexagon-head bolts, about 7 inches long, of manganese bronze. These were submitted by the B. W. S.[a] They were plain extruded by B and upset hot by O.[d]	Many of these bolts were tightened up hard in making ground-flanged joints, probably overstressed. Corrosion had been of very moderate extent only—a brown patina having formed.	These bolts began to fail after only a few days' service and the whole lot remained in service only a short time. During this period approximately 4 per cent of the bolts failed. Nos. 49-58 are samples of nonfailed bolts, whereas Nos. 59-68 had all failed. Failure took place by transverse fracture or fissure (a) at the shoulder of head in Nos. 59, 63, and 66; (b) at the base of thread in Nos. 61, 62, 64, and 68; and by conical fracture (c) in body of bolt in case of No. 67; and (d) at shoulder in No. 65. Fracture was of silky texture in Nos. 65 and 67, fine granular in No. 66 and medium granular in 68.

	Description	Installation	Remarks
M 69-77	⅞-inch diameter tap bolts of manganese bronze, 2½ inches long, submitted by the B. W. S.[a] They were extruded by B.[d]	This lot of bolts was used in making up ground-flange joints and were drawn up only "moderately." Stress most probably below elastic limit. Corrosion had taken place to a moderate degree only.	These bolts failed to the extent of about 62 per cent. These samples are all failed bolts, failure being in all cases by transverse fracture at base of thread; fracture is fine granular.
M 78	½ by 2 inch ladder side bar of naval brass, submitted by the B. W. S.[a], manufactured by C.[d]	Installed in manhole. Corrosion had been slight.	Was received by contractor in 1911, stored until 1912, when it was installed in manhole, apparently sound; in 1913 checks were noticed and bar was removed. These fissures start at edges and extend inward transversely from ⅛ to ½ inch.
M 107-117	⅜-inch diameter hook bolts of naval brass, submitted by the M. F. P.[f] Material supplied by D, work by P.[g]	This lot was installed in the M. F. P.[f] as anchor bolts. Maximum fiber stresses of 15 000 pounds per square inch were probably present, the load being in any case less than one-fifth of the ultimate strength. Corrosion: A dark coating had formed on bolts.	Of this lot approximately 20 per cent failed after from three to four weeks' service. Nos. 107, 110, 111, 113, 114, 115, and 117 failed by oblique fracture at hook; Nos. 108 and 109 failed by oblique fissure at hook; Nos. 112 and 116 failed by transverse fissure at hook; fracture was of silky texture.
M 125-126	1/16-inch strainer plate of naval brass, submitted by the M. F. P.[f] Material by D, work by P.[g]	Installation in M. F. P.[f] Corrosion was not severe; stress not known.	Failures occurred after three to four weeks' service. Failure was by longitudinal fissuring at center of plate (i. e., parallel to direction of working of sheet).
M 131-132	½-inch naval-brass plate with rivets, submitted by B. W. S.[a] Plates cast or rolled by B, flanged by Q, rivets extruded by B.	Riveted and flanged plate forms part of 72-inch riser-pipe expansion joint. Joint was shipped and stored only.	Failure occurred by fissuring of plate where bend had been made in forge, and by breaking off of rivet heads, after storage over winter.
M 134	⅜-inch diameter eyebolt of naval brass, submitted by M. F. P.[f] Material by D, die pressing by P. (?)	Installation in filter plant under approximately 5000 pounds per square inch stress.	Failed after about six weeks' service by transverse fracture at base of thread. Fracture medium granular or crystalline.
M 137-139	⅜-inch naval-brass hook bolts, submitted by M. F. P.[f] Material by D.	These bolts were heated in forge at M. F. P.[f] to cherry red, quenched in warm water, and installed in plant. Stress about 10 000-15 000 pounds per square inch.	Nos. 137 and 138 failed by transverse fracture at base of thread; No. 139 did not fail; they were installed for 60 days under maximum conditions; fracture granular.
M 140-144	⅜-inch diameter naval-brass eyebolts submitted by M. F. P.[f] Material by D.	Installation in M. F. P.[f] Operated at half rate. Load less than 5000 pounds per square inch. Corrosion moderate—only brown patina formed.	After 40 days' service these were removed, and Nos. 142, 143, and 144 were found fractured at base of thread; Nos. 140 and 141 were still sound and had sustained the extra load caused by failure of others; fracture was medium granular.

a New York Board of Water Supply.
b This lot bought under specifications 2 a (Appendix).
c A letter is used to denote manufacturer of bolts.
d This lot bought under specification 2 b.
e This does not mean that the fracture was intercrystalline.
f Minneapolis Filtration Plant.
g This lot bought under specification 3.

TABLE 1—Continued

B. S. No.	Article, material, etc.	Service: Conditions, etc.	Description and extent of failure
M 147–149..	Die-pressed naval-brass ribs, submitted by the M. F. P./ Material by D.	Installation for 40 days in M. F. P./ Corrosion slight.	Nos. 147 and 148 had failed; No. 149 was still sound.
M 150......	1/16-inch strainer plate of naval brass, submitted by M. F. P./ Material by D.	Installed for 90 days in M. F. P./......	Failed by longitudinal fissuring.
M 151–152..	3/8-inch eyebolt, naval brass, submitted by M. F. P./ Material by D.	Installed for 40 days in M. F. P./ Stress about 5000 pounds per square inch.	These bolts failed by transverse fracture at root of thread; fracture granular.
M 156–157..	1¼-inch diameter, 18-inch, naval-brass bolts, submitted by B. W. S.,a Manufactured by B, plain extruded.	Installed in sluice-gate flanges, C. A. Stress not known.	Failure did not occur.
M 158–159..	1¼-inch diameter, 18-inch, manganese-bronze bolts of same lot as above.d	....do......	98 per cent of these bolts failed after one month's service.
M 160–161..	1½ by 26 inch manganese-bronze bolts, submitted by B. W. S.,a Material from F.d	Lot of eight bolts were stored only......	Majority failed by transverse fissuring.
M 162–163..	1 by 38 inch naval-brass bolts, submitted by the B. W. S.,a, d	Storage only......	Failure did not occur.
M 179–180..	1/16-inch naval-brass strainer plate......	Annealed for two hours at from 1000–1300° F. (540–705° C.) before installation.	No failures in annealed material to date.
M 181–183..	1¼-inch naval-brass bolts, submitted by the B. W. S.,a Material by D, manufactured by E. "Cold drawn and annealed." a	Lot of 1200 bolts installed for one year on C. A.,h as anchor bolts.	No failures in this lot.
M 184......	1-inch naval-brass piston rod, submitted by New York Navy Yard.i	In service for two years; stress about 1000 pounds per square inch. Corrosion quite marked.	Specimen did not fail.
M 185–186..	Naval-brass bolts submitted by the B. W. S.,a 7/8 by 38 inch tie bolts, manufactured by D d..	Installed in C. A. from 1912 to 1915......	Specimens did not fail.
M 187–188..	1¼ by 20 inch anchor bolts, manufactured by B d.	Installed in C. A. from 1911 to 1915......	

M 189-190.. M 191-192..	Manganese-bronze bolts, submitted by the B. W. S:a 1¼ by 6⅜ inch stud bolts d.............. 1⅝ by 5½ inch stud bolts, manufactured by A.d	Representing lot of about 130 bolts in service nor several months (C. A.) in ground-flange joints of riser valves. These were probably over-stressed in tightening up. Stress may be estimated at about 15 000 pounds per square inch at the root of thread. Corrosion slight.	No failures occurred in these bolts, although the service conditions were quite comparable to those of lot M 20-39.
M 193-194..	1½ by 7 inch hexagon-head bolts, rolled by B.d	Represents lot of about 500 bolts in service for a few weeks. Of these, some were tightly drawn up, others not so tightly, and some may not have been in service at all. In some cases the bolting stresses may have been 15 000 pounds per square inch.	The service was comparable to that of lot M 49-68. No failures occurred in this lot, however.
M 195-196..	1¼ by 5 inch hexagon-head bolts. Ingots by F, extrusion of rods by B, forging of heads by N.d	Representing lot of about 200 bolts installed in C. A. Paper gaskets were used in making up these flanged joints, and bolting stresses were probably about 10 000 pounds per square inch. Corrosion had been slight—brown patina.	No failures occurred in these bolts.
M 197-198..	1¼ by 5 inch stud bolts. Ingots by F, extrusion by B.d	Representing lot of about 60 bolts installed in C. A. Bolting stresses probably 10 000 pounds per square inch.	No failures of this lot.
M 199-200..	1⅞ by 5½ inch hexagon-head bolts, manufactured by A.:d	Representing lot of 56 bolts on flange joints. Stresses variable, from 5000-15 000 pounds per square inch.	Do.
M 209.....	Manganese-bronze cup rings about 1/16 inch thick, submitted by the B. W. S.a Manufactured by A.	Rings of rolled bronze plate formed by pressing cold over a cast-iron former and then annealed. Installed in riser valve (C. A.).	Cracks appeared parallel to cup bend in Nos. 209a and 209b. No. 209c did not fail under apparently the same conditions.
M 211......	½ by 2 inch ladder side bar, submitted by the B. W. S.a Manufactured by D.	Installed two years in C. A. Stresses very slight. Slight patina.	Found severely checked after two years. Cracks form a regular pattern. (See Fig. 4.)
M 235......	Manganese-bronze U bolt of 1½ inches diameter, submitted by the Panama Canal.	This bolt made by forging of a wrought rod. The stress could not have been more than 17 000 pounds per square inch and was probably about 10 000 pounds. Corrosion was extensive. Supported counterweight of guard valve.	This bolt failed in two places—near U bend and in thread of one upset head. Fracture in body of bolt, mainly fibrous; that in thread, coarse crystalline.

a New York Board of Water Supply.　　b Catskill Aqueduct.

d This lot bought under specification 2 b.

f Minneapolis Filtration Plant.

TABLE 1—Continued

B. S. No.	Article, material, etc.	Service: Conditions, etc.	Description and extent of failure
M 244	1 7/16-inch rolled Tobin-bronze stem, submitted by Norfolk Navy Yard.i	Installed on U. S. S. Rocket. Stress about 4000 pounds per square inch. Temperature up to 300° F. Black patina.	Stem did not fail.
M 245	7/8-inch rolled Tobin-bronze feed-pump stem, submitted by Norfolk Navy Yard.i	Installed in U. S. S. Standish. Stress about 2000 pounds per square inch. Temperature up to 300° F. Black patina.	Do.
M 246	1 1/2 by 60 inch bolt, submitted by the Panama Canal.	Supported counterweight in guard valve. Was removed and tested in tension. Stress about 7000 pounds per square inch.	Did not fail in service.
M 247	1 3/4 by 90 inch manganese-bronze bolt, submitted by the Panama Canal.	Supported counterweight in spillway-gate machines. Stress about 7000 pounds per square inch. Corrosion moderate.	Failed at head, which had been formed by upsetting. Area at fracture greater than at base of thread of opposite end of bolt.

i This lot bought under specifications 1 b (Appendix).

TABLE 2

Description of Materials Which Had Not Been in Service

B. S. No.	Size in inches	Article	Type of brass	Manufacturer	How manufactured
M 80	3/4	Rod	Naval brass	B	
M 81	3/4	...do	...do	B	
M 82	3/4	...do	...do	B	
M 83	1	...do	...do	B	Plain extruded. This is done at a temperature of 1450° F (780° C). The bar is reduced 1/8 inch per pass down to 2 1/2 inches, 1/8 inch per pass down to 1 1/2 inches, and 1/16 inch per pass down to 5/8 inch. About 13 passes per heating are obtained.
M 84	1	...do	...do	B	
M 85	1	...do	...do	B	
M 86	1 1/2	...do	...do	B	
M 87	1 1/2	...do	...do	B	
M 88	1 1/2	...do	...do	B	

No.	Size	Description	Material	Grade	Treatment
M 89	¾	do	do	B	
M 90	¾	do	do	B	
M 91	¾	do	do	B	
M 92	1	do	do	B	Cold drawn. The material is reduced 1/16 inch per pass and annealed at each pass.
M 93	1	do	do	B	
M 94	1	do	do	B	
M 95	1½	do	do	B	
M 96	1½	do	do	B	
M 97	1½	do	do	B	
M 98	¾	do	do	B	
M 99	¾	do	do	B	
M 100	¾	do	do	B	
M 101	1	do	do	B	
M 102	1	do	do	B	Drawn and annealed. The material is annealed at about 1400° F (760° C).
M 103	1	do	do	B	
M 104	1½	do	do	B	
M 105	1½	do	do	B	
M 106	1½	do	do	B	
M 118	1¼	Hook bolt	do	D	
M 119	1¼	do	do	D	
M 120	1¼	do	do	D	
M 121	1¼	do	do	D	
M 122	1¼	do	do	D	
M 123	1¼	do	do	D	
M 124	1¼	do	do	D	
M 127	1/16	Strainer plate	do	D	
M 128	¾	Rod	Manganese bronze	G	Cold rolled and cold drawn to size.
M 129	1	do	do	G	
M 130	1½	do	do	G	
M 135	1¼	Eyebolt	Naval brass	D	
M 136	1	Rod	Manganese bronze	B	
M 145	1¼	Eyebolt	Naval brass	D	
M 146	1¼	do	do	D	

TABLE 2—Continued

B. S. No.	Size in inches	Article	Type of brass	Manufacturer	How manufactured
M 153			Titanium	I	Cast.
M 154	1	Rod	Aluminum	I	
M 155			Bronze		
M 164	1	..do..	Muntz metal	J	Cold drawn and annealed. Worked hot to $1\frac{1}{4}$ inches, drawn cold to $1\frac{5}{16}$ inches, annealed, drawn cold to 1 inch, straightened.
M 165	1	..do..	Naval brass	J	Drawn cold, annealed, drawn. Worked hot to $1\frac{5}{16}$ inches, annealed, drawn cold to 1 inch, straightened.
M 166	1	..do..	Muntz metal	J	Drawn and annealed, drawn. Worked hot to $1\frac{5}{16}$ inches, drawn cold to $1\frac{7}{16}$ inches, annealed, drawn cold to 1 inch, straightened.
M 167	1	..do..	Naval bronze	D	Rolled from $2\frac{1}{2}$-inch casting to $1\frac{7}{8}$ inches, drawn to $1\frac{7}{16}$ inches, annealed, drawn to $1\frac{1}{8}$ inches, $1\frac{1}{16}$ inches, 1 inch, not straightened.
M 168	1	..do..	..do..	D	Rolled from $2\frac{1}{2}$-inch casting to $1\frac{7}{8}$ inches, drawn to $1\frac{7}{16}$ inches, annealed, drawn to $1\frac{1}{8}$ inches, $1\frac{1}{16}$ inches, annealed, drawn to 1 inch, straightened.
M 169	1	..do..	Naval brass	D	Extruded at $1\frac{7}{16}$ inches, drawn to $1\frac{1}{8}$ inches, $1\frac{1}{16}$ inches, 1 inch, no annealing.
M 170	1	..do..	..do..	D	Extruded at 1.008 inches, rolled to size, and straightened.
M 171	1	..do..	Muntz metal	D	Extruded at $1\frac{1}{8}$ inches and drawn to size at one draw without annealing.
M 172	1	..do..	..do..	D	Extruded at 1.040 inches, drawn to 1 inch without annealing.
M 173	1	..do..	Manganese bronze	D	Extruded at $1\frac{1}{8}$ inches, drawn to $1\frac{1}{8}$ inches, $1\frac{1}{16}$ inches, 1 inch without annealing or straightening.
M 174	1	..do..	..do..	D	Extruded at 1.015 inches, drawn to size, straightened without annealing.
M 175	1	..do..	..do..	K	
M 203	1	..do..	Naval brass	L	
M 204	1	..do..	..do..	L	Annealed slightly to remove internal stresses.
M 205	1	..do..	Manganese bronze	L	

TABLE 3

Chemical Analysis and Physical Properties of Brasses

Physical properties (conversion factor, lbs./in.² to kg./cm².... .0703)

B.S. No.	Chemical analysis						Tensile test								Brinell hardness numeral c	
	Copper	Zinc	Tin	Lead	Iron	Manganese	Ultimate strength	Proportional limit a	Yield point	Yield point elongation=3/8 per cent	Yield point elongation=1/2 per cent	Young's modulus	Elongation over 2 inches b	Reduction of area	Center	Edge
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²	Per cent	Per cent		
3	60.0	38.6	0.78	Trace.	0.55	Trace.	70 000	17 000		40 000		16 600 000	33	45		
20							69 500	17 500		32 000	35 000	15 800 000	33	35		
22	56.6	40.8	1.16	Trace.	1.36	0.03										
23	56.4	40.9	1.25	Trace.	1.43	.03										
24							68 000	18 000		32 500		13 300 000	40	44		
28	58.1	39.7	.91	Trace.	1.33	Trace.										
32	56.8	40.5	1.14	Trace.	1.50	.02										
34	56.8	40.6	1.10	Trace.	1.47	.03										
39	56.9	40.5	1.17	0.13	1.30	Trace.										
41	56.4	40.7	1.15	Trace.	1.71	.03										
43	56.4	40.8	1.02	Trace.	1.71	.03										
49	58.3	40.2	.76	Trace.	.76	Trace.										
50							72 000	35 000		36 000	37 500	12 400 000	34	36		
54	58.6	39.9	.72	Trace.	.76	Trace.										
63							71 500	26 000		32 500		12 900 000	34	39		
67	58.3	40.2	.78	Trace.	.72	None.										
68	56.6	41.5	.90	Trace.	.94	None.	51 500	32 000				13 200 000				

a This point is taken as the stress at which the stress-strain curve departs from a straight line by an amount equivalent to an elongation of about 0.00005 inch in 2 inches or 0.0025 per cent.

b The elongation and reduction of area are given here only to the nearest per cent.

c Load of 1000 pounds was used.

TABLE 3—Continued

Physical properties (conversion factor, lbs./in.² to kg/cm²..... .0703)

B.S. No.	Chemical analysis — Copper	Zinc	Tin	Lead	Iron	Manganese	Tensile test — Ultimate strength	Proportional limit	Yield point	Yield point elonga-tion=⅜ per cent	Yield point elonga-tion=⅓ per cent	Young's modulus	Elongation over 2 inches	Reduction of area	Brinell hardness numeral — Center	Edge
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²	Per cent	Per cent		
71	58.8	39.5	0.82	0.19	.60	None.										
74	58.9	39.5	.80	Trace.	.80	Trace.										
78																
83	60.9	38.3	.61	.17	Trace.	None.	58 500	d 21 000	e 30 000	23 000	24 000	15 400 000	49	59		
85	59.8	39.3	.67	.16	Trace.	None.	61 000	d 16 000	e 34 000	17 500		16 000 000	46	50		
92	60.9	38.3	.61	.17	Trace.	None.	58 500	d 26 000	e 35 900	28 000	29 000	16 500 000	46	56	86.4	88.2
94	59.8	39.3	.67	.16	Trace.	None.	61 500	d 16 000	e 33 500	22 500		15 400 000	45	52		
101	60.9	38.3	.61	.17	Trace.	None.	57 000	d 18 700	e 31 200	20 000		14 500 000	49	54	83.1	84.6
103	59.8	39.3	.67	.16	Trace.	None.	62 000	d 10 000	e 33 500	22 500		14 800 000	43	47		
122	60.3	38.9	.68	.15	Trace.	None.										
127	59.8	39.5	.65	.10	Trace.	None.										
129	59.2	38.8	.97	Trace.	1.00	Trace.	79 000	25 000		32 500	36 000	16 000 000	23	43		127.6
136	59.1	39.3	.78	.13	.70	None.	72 000	27 500	e 48 000	40 000		12 500 000	44	50	120.5	83.1
156	61.1	38.2	.72	Trace.	Trace.	None.	55 500	d 14 000		22 000		11 900 000	f 43	52	80.8	81.6
157	61.2	38.0	.78	Trace.	Trace.	None.	55 000	d 19 000		19 000	20 000	14 300 000	f 41	31	80.4	136.8
158	57.9	40.4	.74	1.08	1.00	None.	66 000	32 500		35 000	37 000	g10 400 000	f 31	41	127.6	135.1
159	57.6	40.5	.87	1.08	1.08	None.									125.2	127.5
160	57.3	40.7	.94	Trace.	1.08	Trace.	61 000	14 000		26 000	28 000	13 600 000	f 28	30	122.8	124.4
161	58.4	39.8	.83	Trace.	.94	None.	67 500	23 000		35 000		g27 300 000	f 25	34	122.8	125.2
162	60.3	39.1	.60	Trace.	None.	None.	65 000	40 000		45 000		18 700 000	f 28	49	119.0	128.4
163	60.3	39.1	.53	Trace.	None.	None.	61 000	34 000		42 500		13 900 000	f 25	45	119.8	

No.																
164	61.1	38.5	None.	.36	.05	....	72 000	40 000	h 73 500	45 000	....	17 400 000	f 16	50	136.8	139.7
165	62.3	36.8	.72	.07	.03	....	56 000	27 500	h 42 300	35 000	....	16 200 000	f 40	54	91.0	100.5
166	61.1	38.6	None.	.29	.05	....	61 000	37 000	h 50 200	42 500	....	17 600 000	f 33	52	107.0	112.7
167	60.1	39.1	.76	.05	.02	....	78 500	26 000	i 59 500	47 500	....	14 300 000	20	41	f 143.0	f 160.0
168	60.5	38.6	.76	.10	.03	....	64 500	a 36 000	i 45 000	40 000	....	14 700 000	33	45	i 105.0	f 124.0
169	61.2	37.5	1.15	.08	.03	....	83 000	34 000	i 62 500	50 000	....	14 600 000	13	30	f 158.0	f 176.0
170	61.3	37.4	1.21	.10	.03	....	68 000	a 44 000	i 42 000	44 000	45 000	17 900 000	31	47	f 109.0	f 130.0
171	59.4	40.2	None.	.33	.02	....	80 000	39 000	i 54 000	50 000	....	14 000 000	21	41	f 158.0	f 158.0
172	59.4	40.2	None.	.35	.02	....	64 000	a 36 000	i 42 000	40 000	....	16 200 000	40	50	f 100.0	f 114.0
173	56.8	39.9	1.63	.11	1.27	.22	100 500	20 000	i 63 000	47 500	....	15 000 000	9	14	f 143.0	f 150.0
174	56.9	40.1	1.63	.07	1.18	.14	84 000	a 36 000	i 54 000	47 500	55 000	15 400 000	22	20	f 119.0	f 130.0
175	57.5	40.9	1.00	Trace.	.60	Trace.	77 000	26 000	....	35 000	....	11 400 000	27	27	130.7	136.1
181	61.2	38.1	.70	Trace.	Trace.	None.	54 500	a 18 700	....	20 000	21 000	15 600 000	52	52	77.6	80.8
182	60.6	38.7	.70	Trace.	Trace.	None.	55 500	a 16 000	....	24 000	25 000	14 800 000	48	49	84.2	85.0
183	61.0	38.3	.70	Trace.	Trace.	None.	57 500	a 21 000	....	20 000	....	17 900 000	47	44	80.0	82.0
184	61.6	37.6	.70	Trace.	.07	....	61 800	a 28 700	....	40 000	....	18 200 000	23	23	120.5	122.9
185	61.0	38.2	.80	Trace.	Trace.	None.	58 500	a 21 000	....	30 000	....	17 700 000	42	47	100.5	103.3
186	62.0	37.3	.70	Trace.	Trace.	None.	56 500	a 23 700	....	30 000	....	17 500 000	48	54	90.8	97.7
187	60.0	39.6	.40	Trace.	Trace.	None.	64 600	a 28 700	....	37 500	....	16 500 000	33	45	119.0	125.2
188	60.8	38.8	.40	Trace.	Trace.	None.	61 700	a 25 000	....	32 500	....	16 700 000	43	55	100.5	108.2
189	56.6	40.8	1.00	.10	1.50	.02	61 600	24 000	....	....	....	14 500 000	....	....	....	....
190	57.7	39.9	1.10	Trace.	1.30	.02	69 500	a 18 700	....	22 500	....	19 200 000	37	37	....	....
193	56.8	41.4	.70	Trace.	1.10	None.	....	....	....	....	....	....	....	....	....	....
194	56.4	41.7	1.00	.10	.80	None.	76 200	a 31 200	....	35 000	....	12 500 000	33	37	....	....
195	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
196	....	....	....	....	....	None.	71 000	a 21 300	....	27 500	....	16 400 000	39	48	....	....
197	57.9	40.5	.70	.10	.80	None.	....	....	....	....	....	....	....	....	....	....

a The mean of a range as reported is here given. This range was generally 2000 pounds per square inch.

e These determinations were made by the manufacturer by the caliper method.

f In this case a 3-inch gage length was used.

g This determination was made with a 1-point extensometer and is without doubt in error. His definition of yield point is that stress at which permanent deformation takes place.

h These determinations were made by the manufacturer. His definition of the yield point as that value of the stress at which total elongation of ½ per cent or $\frac{1}{180}$ inch in 2 inches is obtained. He states "that in 60:40 brasses experience has indicated that after ½ per cent elongation is produced rapid extension sets in."

i These determinations were made by the manufacturer, who defines the yield point as that value of the stress at which total elongation of ½ per cent or $\frac{1}{180}$ inch in 2 inches is obtained.

j These determinations were made by the manufacturer under different conditions than those indicated above; they are, however, comparable among themselves.

TABLE 3—Continued

Physical properties (conversion factor, lbs./in.² to kg/cm².....0703)

B.S. No.	Chemical analysis						Tensile test								Brinell hardness numeral	
	Copper	Zinc	Tin	Lead	Iron	Manganese	Ultimate strength	Proportional limit	Yield point	Yield point elongation=⅜ per cent	Yield point elongation=⅝ per cent	Young's modulus	Elongation over 2 inches	Reduction of area	Center	Edge
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²	Per cent	Per cent		
198	57.9	40.4	0.80	Trace.	0.90	None.	67 000	d 20 000	......	25 000	......	12 900 000	35	40	......	......
199	58.2	40.0	.90	Trace.	.90	None.	......	......	......	......	......	......	......	......	......	......
200	58.1	40.2	.80	Trace.	.90	None.	68 600	d 19 000	......	27 500	......	13 400 000	38	41	......	......
203	61.1	38.3	.52	0.09	.02	......	70 700	44 000	......	......	......	14 000 000	31	57	126.7	137.7
204	61.6	37.5	.73	.13	.02	......	62 200	29 000	......	......	......	14 500 000	39	40	127.4	108.8
205	58.8	39.6	.39	.13	1.06	None.	84 600	52 000	......	......	......	15 400 000	22	41	148.4	156.7
235	......	......	......	......	......	......	62 000	19 000	......	......	28 500	14 600 000	43	52	......	......
244	60.6	38.6	.80	Trace.	Trace.	None.	68 500	22 000	......	......	45 000	14 900 000	29	44	......	......
245	62.2	37.1	.60	.10	Trace.	None.	60 000	24 500	......	......	37 000	15 900 000	41	56	......	......
246	59.0	40.2	.70	.10	Trace.	None.	63 500	27 500	......	......	37 000	13 700 000	33	41	......	......
247	57.2	40.7	.90	.10	1.10	Trace.	86 000	43 000	......	......	......	15 300 000	k 13	14	145.0	154.0

d The mean of a range as reported is here given. This range was generally 2000 pounds per square inch.
k Elongation was measured over 6 inches.

1. INTERNAL, INITIAL STRESSES

Initial stresses are introduced into metallic articles in a variety of ways. They may be the consequence of the cooling of different parts of an object at different rates (shrinkage stresses), or of the cooling at the same rate of a heterogeneous material consisting of two or more constituents of different coefficients of expansion. They may be the result of unequal degree of plastic deformation in different parts of an object, such as in a cold-rolled rod, in which the outer layers receive more "work" than the inner ones.

Their magnitude and distribution may then be said broadly to depend upon two factors, one, the "process" factor which includes those details of manufacture which determine the rate of cooling of materials, the amount and number of reductions in working or forging, the temperature at which the work is done, etc.; the other, the material factor, those properties of the material, elastic limit, ductility, toughness, etc., which determine the degree to which materials are sensitive to the manufacturing operations. Considering wrought materials, one may cite under the first factor, details such as the shape of dies or rolls, amount and number of reduction between anneals, time and temperature of annealing, rate of cooling after annealing or forging, etc.

The distribution of such stresses may be quite complicated, as Howard [18] has shown. When any portion of such an initially stressed object is removed a partial relief of these stresses takes place through the warping of the object. This warping of cold-worked brass upon machining is well known to instrument makers, who frequently have to regrind close-fitting parts frequently before a permanent fit is secured. The warping due to such stresses may occur at least to a slight degree also merely upon standing. In constructing a brass plate condenser for precision work, Dr. H. L. Curtis, of this Bureau, found that such a condenser made up with ordinary hard brass sheet did not possess a constant electrical capacity (which depends upon the distance between the brass plates), but that the latter kept constantly changing, showing that the plates, although well supported, were gradually warping. Upon annealing these plates at about 250° F (120° C) no further variations in capacity were noticed.

In the case of wrought rods, particularly as drawn or extruded, the distribution of these stresses is simple, as they are radially symmetrical. This fact facilitates markedly the measurement of

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[18] Loc. cit.

their value, as it is possible, as Heyn has shown, to calculate these values from the changes in length of such rods during the removal of annular cylindrical layers.

(a) *Measurement and Calculation.*—The stresses measured in this way are the stress components parallel to the axis of the rod, and may be called the longitudinal or axial initial stresses as distinguished from tangential or radial ones.

The measurement of the stresses in the brass materials investigated were made by the Howard-Heyn method.[19]   In Fig. 9 is shown a specimen after the series of measurements has been made. The metal is turned off over the length *a;* if there is longitudinal stress in the layers turned off, these stresses will be relieved and the whole bar will elongate or contract.   These length changes were, in general, measured by means of an end comparator between the polished ends of the bar *A* and *B*, in some cases, however, by line comparator or by strain gage.   As the ends, after machining, were not perfectly parallel, the same end points or areas had to be used for successive measurements; this was made possible by scribing lines on the ends: two concentric circles and two pairs of parallel-straight lines at right angles, as shown in Fig. 5. In this way four areas are given on each end, and the distances between each corresponding pairs were measured after each machine cut.   The value taken was the average of these four unless otherwise stated.   In this way correction was made for any eccentric distribution of the stresses.

It was found that certain precautions were necessary in machining the specimen.   It was necessary to take a light cut for two reasons, first, in order that the temperature of the specimen might not rise too much during machining, and second, in order that there should be a minimum possibility of introducing stresses at the surface of the machined bar by the tool pressure.   A cut of 0.005-inch feed and lead was practically uniformly adhered to, with a speed of about 500 r.p.m. (60 to 125 linear feet per minute).

The temperature of the surface near the tool was not allowed to become so warm that the hand could not be kept on it, and the bar was cooled with an air blast or water when the temperature threatened to go above this point.   Thus was prevented the possibility of any annealing action going on during the machining.

It was noticed in the preliminary experiments that the use of the ordinary form of dog in gripping the specimen on the lathe was

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[19] Such measurements were first made on Harveyized steel bar by Howard (tests of metals, Watertown Arsenal, 1893, p. 285); Heyn independently developed the method further.   Martens-Heyn, Handbuch der Materialienkunde, loc. cit.
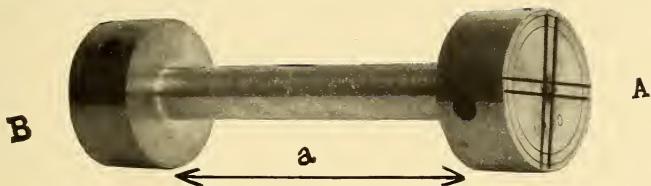
FIG. 9.—*Form of specimen used in measuring initial stress*

FIG. 10.—*Specimen for rapid initial stress test on bars*

not advisable, as the compression of the specimen by it caused in itself an appreciable elongation. It was necessary to use a special device, which consisted of a piece of one-fourth inch steel wire bent to a right angle. One arm was bolted to the face plate of the lathe and the other went through a transverse hole in one end of the brass specimen and was lightly secured therein by bolts. This arrangement, it was observed, introduced no errors in the measurements.

The length $\overline{AB}$ of the specimen over which it was turned down varied from 5 to 25 cm.

The stresses in each layer were calculated from the formula [20]

$$S = \frac{E}{l'} \; \frac{d_n^2 \, (l_n - l_o) - d_{n-1}^2 \, (l_{n-1} - l_o)}{d_{n-1}^2 - d_n^2}$$

A consideration of the sources of error of such measurements shows that there are three principal kinds:

(1) Errors due to temperature variation;

(2) Errors in length measurements on the comparator;

(3) Errors in the determination of the modulus of elasticity.

The error due to (1) was very small as care was taken to secure a uniform temperature over the specimen and to measure this temperature to 0.1° C. The probable error in the length measurements was about 0.3 to 0.5 μ (about 0.000012 to 0.00002 inch). This corresponds in the majority of cases to a probable stress error of about ±300 to 500 pounds per square inch, although in a few cases where short lengths were taken this error would be from ±600 to 1000 pounds per square inch. The probable stress error is directly proportional to any possible error in the modulus which is probably about ±3 per cent. The total probable error in any one measurement can be assumed to be about ±3 to 4 per cent.

In a few cases the specimens were too small or irregularly shaped to be turned in a lathe, and in these cases the metal was etched off with dilute nitric acid and the length measurements made with a line comparator. In such cases the error due to irregular cross section, etc., may have been much greater, as much, possibly, as 50 to 100 per cent.

[20] Where S=stress
  E=the modulus of elasticity
  l'=length over which the specimen is turned down
  d_n=diameter of turned down part after the nth machine cut
  l_n=length of bar after nth machine cut
  l_o=original length of bar
A plus value for S indicates a tensional stress in the corresponding layer.

In several cases a strain gage was used, in which cases the probable stress error due to a lesser accuracy of the length measurement may have been 5000 pounds per square inch.

In some cases the value of E could not be determined on the same bar which had been used in the determination of initial stress, and the value of E of other samples of the same lot had to be used. This introduces an unknown error which probably will not exceed at the maximum ±12 per cent.

Values obtained from measurements made under the less favorable conditions of this sort will be indicated in the tables below.

There is obtained by such measurements a value of the internal stress for each annular or rectangular layer, which may best be presented in the form of diagrams in which the stresses for each layer are plotted as a function of either the diameter [21] of the annular layer, or of this diameter squared, as Heyn has done. For convenience in obtaining average values of the initial stresses we have chosen to use Heyn's method and plot the stresses as a function of the diameter squared.

Such a diagram is given in Fig. 97 for M 3. The outer layer of this 1.25-inch rod was in tension from the edge, at a diameter of $\sqrt{1.57} = 1.25$ inches, to the neutral point, which lay at a diameter of $\sqrt{0.82} = 0.905$ inches. The average value of that tension was 25 000 pounds per square inch, the maximum value, 44 000 pounds per square inch. From the neutral layer to the center the metal was in compression.

TABLE 4

Initial Stress Measurements Made on Different Samples of the Same Manganese-Bronze Rod

B. S. No.	Distance of sample from end of bar		Length of sample	Method of procedure	Initial stresses					
					Average stress		Maximum tension		Maximum compression	
	Feet	Ins.	Inches		lbs./in.²	kg/cm²	lbs./in.²	kg/cm²	lbs./in.²	kg/cm²
136–2......	0	6	5	Turning down.	22 200	1560	34 000	2390	32 000	2250
136–24.....	10	0	5	.....do........	22 000	1540	36 000	2530	32 000	2250
136–50.....	14	0	2½	.....do........	25 000	1750	38 000	2670	34 000	2390
136–51.....	14	2½	10	.....do........	22 800	1600	38 800	2730	29 300	2060
136–a......	11	0	5	Boring out.....	20 500	1440	22 800	1610	36 600	2580
214–1......	......	......	10	Turning down.	22 500	1580	37 500	2630	23 400	1640
214–2......	......	......	10	Boring out	21 300	1490	30 200	2120	29 500	2050

(b) *Values of Initial Stresses.*—Diagrams are shown for typical materials tested in Figs. 97 to 120.

[21] For rectangular or square rods one would use one transverse dimension in place of the diameter.

In order to ascertain what agreement could be obtained in the measurement of these stresses on the same material by different methods and over specimens of different length, several measurements were made of these stresses in specimen M 136, a 20-foot length of 1-inch diameter manganese-bronze round rod. The position and length of these samples, the method of procedure in machining, and the results of the measurements are given in Table 4, and an idea of the agreement between the results of these tests may be obtained from the initial stress diagrams, Figs. 103 to 110. It is seen that although individual layers will often possess stresses of different value in different parts of the rod, the average value of the stresses agrees very closely, as can be seen by reference to the table below. In particular, these results indicate (1) that the results by boring out and turning down are almost identical, with the precautions observed, (2) that the end effects [22] are limited to a very small length at the ends, since the values of the stresses on adjacent samples of lengths 2½ and 10 inches, respectively, show good agreement. In fact, the average stress in the small specimen, M 136–50 is greater than in the adjacent 10-inch sample, No. 136–51, which is the reverse of what would be expected if the stresses were much lower near the ends of the test specimen.

Another set of determinations was made on adjacent 10-inch length of 2-inch diameter round Tobin bronze rod, in order to determine what agreement would be found between the results obtained by machining down and by boring out a rod. These results are also given in Table 4 and in the stress diagrams Nos. 109 and 110. Apparently the variations in values are within the limits of experimental error or of the variation of uniformity of the bar itself.

Although the initial stress diagram alone completely describes the state of initial stress (as regards longitudinal stresses) in a bar or rod, it is possible to choose certain values of these stresses which may serve as at least approximate characteristics. Such are the maximum tension, the maximum compression, the stress value in the outermost layer, and the average stress (without regard to sign). The maximum values are not generally conveniently possible of accurate determination, for the reason that these maxima are attained in a very thin layer only of the material,

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[22] Dr. G. R. Olshausen has suggested that at the ends the stresses must be zero in value, and the actual, original value (i. e., before the bar was cut at these ends) of the stress in any layer is reached only at some distance from the ends. What is measured is an average value, over a length of rod which may include a part of the rod near the ends in which this variation of stress is taking place.

which layer is included together with adjacent ones, containing lower stresses, in the larger one machined off. It would be necessary, in order to determine maxima accurately, to take infinitely thin steps in machining.

The Table 5 contains these four principal values of the initial stress in each specimen tested. A column indicates which kind of stress exists in the outer layer (C = compression, T = tension).

TABLE 5

Principal Values of the Initial Longitudinal Stresses in Brass Materials

[Conversion factor, lbs./in.² to kg/cm²...... .0703]

B. S. No.	Average stress	Maximum tension	Maximum compression	Stress in outer layer	T=Tension C=Compression	Remarks
	lbs./in.²	lbs./in.²	lbs./in.²	lbs./in.²		
2..........	18 800	60 500	....	60 500	T	
3..........	25 000	44 000	33 000	32 000	T	
22 *a*........	18 400	28 400	28 200	27 500	C	
23 *a, b*......	15 400	24 500	31 600	18 000	C	
28 *a*........	5500	7500	8500	8430	C	
32 *a*........	17 900	20 500	26 500	26 400	C	
34 *a*........	18 700	26 500	25 500	16 000	C	Material of which from 4 to 83
41 *a*........	4400	32 000	5500	5600	C	per cent failed in service.
43 *a*........	2500	4500	5500	400	C	
49 *a*........	3100	3500	7000	6500	C	
54 *a*........	1600	5000	6500	5100	T	
67 *a*........	6400	12 000	11 000	12 400	T	
68 *b*........	3900	7500	9000	5500	C	
74 *c*........	15 700	17 000	21 500	9800	C	
78 *c*........	9500	29 500	6500	29 600	T	
83..........	1000	2500	1500	2700	T	
85..........	2000	7000	6000	1400	T	
92..........	750	1250	1000	1400	T	New material.
94..........	750	2000	1200	2000	T	
101..........	1870	8000	2000	8200	T	
103..........	2300	13 300	5800	13 000	T	
116 *c*........	9900	7500	15 000	15 000	C	
118 *c*........	8500	46 000	19 500	46 000	T	About 20 per cent failed in service.
125 *c*........	4300	3500	5500	5800	C	
129..........	14 600	20 000	24 000	22 000	C	New material.
131–L.......	17 600	19 500	59 000	59 000	C	
131–T.......	1500	5500	2500	5600	T	
136 *b*........	22 200	34 000	32 000	27 000	T	
138 *c*........	500	2500	450	2500	T	
140 *c*........	18 000	46 000	42 000	46 000	T	20 per cent failed.
142 *c*........	30 300	29 500	70 000	29 200	T	
156..........	3000	15 000	11 500	15 000	T	
157..........	3100	5100	7700	6000	T	
158..........	....	43 000	....	9000	T	From lots of failed material.
160..........	30 300	84 000	38 700	83 000	T	
161 *d*........	....	53 000	....	26 000	T	

a The determination of E was made on samples of the same lot, but not on bolt tested for initial stresses.

b These materials had nonsymmetrical stresses over 2000 to 3000 pounds per square inch. (See p. 36.)

c The value of E was assumed to be 16 000 000 pounds per square inch.

d The value of E was assumed to be 15 000 000 pounds per square inch.

TABLE 5—Continued

B. S. No.	Average stress	Maximum tension	Maximum compression	Stress in outer layer	T=Tension C=Compression	Remarks
	lbs./in.²	lbs./in.²	lbs./in.²	lbs./in.²		
162.	2750	6000	15 500	7000	C	}Material did not fail.
163..........	2900	3000	11 500	1000	C	
164..........	12 000	14 000	33 000	11 000	C	
165..........	9600	9600	26 000	27 000	C	
166..........	13 100	17 500	28 000	26 000	C	
167..........	32 600	56 500	44 500	56 000	T	
168..........	3500	5100	6000	7000	C	
169 b	42 500	94 000	44 000	42 000	T	}New material.
170..........	6600	11 900	10 000	10 000	C	
171..........	15 700	32 500	22 500	12 000	T	
172..........	4200	6100	10 800	11 000	C	
173..........	37 500	65 500	53 500	40 000	T	
174..........	3380	9000	9000	8000	C	
175..........	5600	9000	8400	9000	T	
181..........	2400	4300	5800	2500	T	
182..........	1100	3000	3000	3500	T	
183..........	1100	3700	1500	2000	C	
184..........	3800	5000	8000	8000	C	
185..........	1900	3000	4500	4500	C	
186..........	2000	1700	6500	6000	C	Brass bolts, representing lots
187..........	5620	6500	14 000	13 000	C	of some 1000–1500 bolts which
188..........	5270	7500	11 800	12 000	C	have not failed in service.
189..........	7700	9800	12 000	12 000	C	
193 a ......:	3600	4500	4500	3000	C	
195 a	5200	6000	8000	8000	C	
197 a	3400	3200	5500	3000	C	
199 a	1950	3200	2500	2000	C	
201-A c......	5500	4500	7000	4500	T	
203..........	5400	7800	9200	7500	T	
204..........	4900	7200	11 700	12 000	C	}New material.
205 b	5500	6000	9300	4000	T	
235..........	3630	....	11 200	11 200	C	
244..........	5300	9850	8700	8700	C	
245 b	2280	6900	35 600	35 600	C	}Failed material.
246..........	4400	....	16 100	16 100	C	
247..........	1100	....	5400	5400	C	

a The determination of *E* was made on samples of the same lot, but not on bolt tested for initial stress.
b These materials had nonsymmetrical stresses over 2000 to 3000 pounds per square inch. (See p. 36.)
c The value of *E* was assumed to be 16 000 000 pounds per square inch.

A very wide variation, both in magnitude and in distribution of these initial stresses, is noticed from the table, corresponding to the variation in the countless details of manufacture.

The distribution of the initial stresses is interesting and gives an indication as to the mode of manufacture of the material. Drawing cold introduces tension on the outside and compression on the inside, whereas extrusion produces the reverse effect. The rods Nos. 3, 136, 160, 167, and 173 have been finished by heavy

cold drawing, whereas the work done on the others was largely extrusion followed by a draw to size. The effect of this final draw can always be seen in the displacement of the stress values at the surface toward tension. In some cases—for example, No. 67—the final draw has been sufficient to neutralize the compression at the surface resulting from extrusion and produce actual tension; in others—Nos. 32, 43, 164, etc.—the final draw has only succeeded in partially neutralizing these surface compressional stresses.

(c) *Radially Nonsymmetrical Stresses.*—It was noticed in the measurement of the length changes which took place upon machining that these were not always the same in value for the four positions. In the great majority of cases these differences were small and could be explained by a slight inaccuracy in centering the bar for machining, such that the layers turned off were not concentric to the true center of the rod. In some cases these differences were, however, too large to be accounted for in this manner and were due to an eccentric distribution of stress which can be approximately described as consisting of a system of radially symmetric stresses superimposed upon two sets of initial resisting moment stresses, referred to two neutral diametral planes at right angles to each other. These latter may be looked upon as initial bending stresses, and their values were calculated in the cases in which a great variation in the elongation or contraction along opposite fibers gave evidence that they were of large value.

· In so doing use was made of an equation[23] similar to the one on page 31, and which is given below.

$$S_n = \frac{E}{4} \frac{(d_{n-1} + d_n)}{Dl \ (d^4_{n-1} - d^4_n)} [d^4_{n-1} \ (l^A_{n-1} - l^C_{n-1}) - d^4_n \ (l^A_n - l^C_n)]$$

This equation was derived by considering that the specimen is built up of concentric annuli of differing unit stresses, hence of differing resisting moments, which, however, in summation equal zero; expressing this fact

$$\frac{S_1 I_1}{C_1} + \frac{S_2 I_2}{C_2} + \cdots \frac{S_n I_n}{C_n} + \frac{S'_n I'_n}{C'_n} = 0$$

[23] Where

S_n = average fiber stress in nth layer contributing to a resisting bending moment only.

E = the modulus of elasticity.

D = transverse distance between opposite pair of points A and B (i. e., 1 and 3 or 2 and 4 in Fig. 5) on ends of bar, at which length measurements were made.

l = length of bar.

d_n = diameter after nth machine cut.

$\left.\begin{array}{l} l^A_n \\ l^C_n \end{array}\right\}$ Total elongations of bar after the removal of the nth layer at the points A and C, respectively.

Where S is the fiber stress at a distance C, and I, the moment of inertia of the section. The subscripts refer to the successive layers or annuli, and the term $\dfrac{S_n' I_n'}{C_n'}$ to that cylindrical part of the bar remaining after turning off the nth layer.

Considering now that $S_n' = \dfrac{E\,C_n'}{R_n}$

where R is radius of curvature of bar originally straight, and is equal to

$$\frac{D1}{1_n^A - 1_n^C} = R_n$$

using the proper values for I and combining the above equations, the full equation is obtained.

Although these stresses as so measured were of little significance in the majority of cases, as mentioned above, amounting to in maximum ± 1000 pounds per square inch, mention is here made of them and the measurements made of them to show that a false impression of the longitudinal initial stresses may be obtained by noting the average change of length only in such measurements. In materials Nos. 23, 136–2, and 169 such bending (fiber) stresses were found amounting to at maximum ± 16800, ± 8000, and ± 18000 pounds per square inch, respectively.[24] These stresses must be added algebraically to the average longitudinal fiber stresses in order to obtain the true stress at any points. These bending stresses of large value are probably introduced into the rods during straightening.

(d) *Rapid Methods for Initial-Stress Determinations.*—The importance of having methods, which are quick and convenient, by which materials may be tested for the presence of internal stresses will at once be realized. The layer-by-layer method is the only accurate one as yet known, but it is much too slow for inspectional work, for example.

Instead of so measuring the stresses the average value only may be measured, only one layer being removed by machining in this case, of which the area is equal to 0.5 of the total area. In the great majority of cases the initial stress changes sign at about that value of the diameter—that is, 0.7 of the original diameter—at which the remaining cross-sectional area is 0.5 of the original. A strain gage can be used in this case, with gage points on two opposite fibers. For an 8-inch gage, for example, the specimen

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[24] The presence of such nonsymmetrical stresses of significant value is noted (*b*) in Table 5.

should be 10 inches long; if a layer 7 inches long is removed, the average stress would be

$$S = \frac{E}{l'}\left(\frac{d_n^2}{d_n^2 - d^2}\frac{(l_n - l_0)}{d_n^2 - d^2}\right)$$

$$= \frac{E}{7}(l_n - l_0)$$

A stress value of 2000 pounds per square inch would give a change in length of 0.001 inch.

A second method of obtaining a value of the initial stresses was suggested by S. W. Miller, of the Rochester & Mohawk Welding Works, and tested by us on samples of known initial-stress distribution. This method depends upon the fact that a portion cut longitudinally from a round rod, and having a sector section similar to that in Fig. 10 will bend, such that the outer surface, originally straight, will be convex or concave, depending upon whether compression or tension were originally present in the outside layers. In Fig. 10 is shown specimen M–136 with such a section of 30° angle removed over a length of 5 inches. The concave curvature of the piece removed is easily seen.

Making the assumption that bending takes place around a neutral plane passing through the center of gravity of the section, there can be calculated the change of the stress in either outside original surface fibers or inside original ones caused by the bending. These are, respectively,

$$\Delta S_0 = \frac{Er}{3R} = \frac{8E}{3L^2}\frac{\delta r}{}$$

$$\Delta S_i = \frac{2Er}{3R} = \frac{16E}{3L^2}\frac{\delta r}{}$$

where
ΔS_0, ΔS_i = changes in stress at outer and inner fibers, respectively.

    E = modulus of elasticity.

    R = radius of curvature produced by bending.

    δ = bending at center in linear measure.

    L = length of specimen.

    r = radius of rod.

Three 5-inch specimens were so tested and the results so calculated are compared in Table 6 with those obtained by the comparator method. The assumption is further made in this table that the larger fraction of the initial stresses is released by the bending, such that the calculated change in stress is equal approximately to the original stress. Naturally these assumptions hold

the better, the nearer the actual initial stress distribution corresponds to a linear one with a change of sign of stress at the neutral axis passing through the center of gravity.

TABLE 6

Comparison of Measurements of Initial Stress by Two Methods

B. S. No.	Initial stresses [a] as measured by comparator method			Amount of bending at center of 5-inch specimen	Initial stresses [a] by release-bending method	
	Average stress	Maximum stress near surface	Maximum stress near center		Outer surface	Inner edge
	lbs./in.²	lbs./in.²	lbs./in.²	inches	lbs./in.²	lbs./in.²
136............	22 250	+34 000	−32 000	0. 0350	+30 000	−60 000
168............	3500	− 6000	+ 5100	. 0510	− 4720	+ 9400
169............	42 500	+94 000	−44 000	. 0059	+41 000	−82 000

[a] The signs refer to the kind of stress; + signifies tension.

From the table it is seen that for these materials there is good agreement between the maximum stress values at or near the outer surface, but not at the center, where the release-bending method gives them uniformly too high. This test is recommended as being the quickest method known of obtaining an approximate idea of the value of the initial stresses.

One must not overlook in these last two methods described their inherent faults. It is possible to obtain false results by both methods when the initial stress changes sign more than once and by the Miller method when the stress distribution differs widely from a linear one, with neutral point at a distance from the center equal to 70 per cent of the radius. Some sacrifice in accuracy must be made when rapidity and ease of manipulation are desired.

(e) *Removal of Initial Stresses by Annealing.*—Experiments were made to ascertain under what conditions of annealing the initial stresses could best be removed. From one manganese-bronze material, No. 136, of which a 20-foot length of rod was supplied, several 5-inch lengths were taken and annealed for different periods at several temperatures. Initial stress measurements and tensile tests were then made on the specimens so treated.

The Table 7 contains the results so obtained. The initial stress diagram for 136–6, annealed for one hour at 400° C, is given also in Fig. 108. The values given in the Table 7 of the average initial stresses are plotted in Fig. 11 as a function of the

annealing temperatures. It is seen (1) that temperatures of from 300° to 400° are sufficient to reduce in from one to seven hours the initial stresses to a safe value, and (2) that annealing for from one to seven hours at 400° C does not soften this material in the sense of reducing either the ultimate strength or the proportional limit. It is thus possible to anneal this brass material in such a manner as to remove the internal stresses and yet not affect the mechanical properties. No significance is probably to be attached to the initial rise of curve No. 1 in Fig. 11. It is probable that the original average stress in this sample was actually higher than that of the two original samples tested.

TABLE 7

Effect of Annealing on Properties of 1-inch Manganese-Bronze Rod

B. S. No.	Time of annealing	Temperature of annealing	Average stress	Maximum tension	Maximum compression
	Hours	°C	lbs./in.²	lbs./in.²	lbs./in.²
136–2	(a)	(a)	22 250	34 000	32 000
136–24	(a)	(a)	22 200	36 000	32 000
136–8	1	100	24 700	31 400	38 500
136–16	7	100	18 250	65 000	35 000
136–3	24	110	16 800	29 000	24 300
136–17	1	170	17 200	29 000	23 500
136–9	7	170	11 400	17 500	16 600
136–12	1	232	5500	8100	7000
136–20	7	232	3100	3500	5000
136–10	1	360	1470	5000	1500
136–18	7	360	150	1000	200
136–6	1	400	1200	5600	1000
136–14	7	400	100	100	500
23	(a)	(a)	15 400	24 500	31 600
23 A	½	600	3000	11 000	16 500

B. S. No.	Time of annealing	Temperature of annealing	Ultimate strength	Proportional limit	Elongation in 2 inches	Reduction of area
	Hours	°C	lbs./in.²	lbs./in.²	Per cent	Per cent
136–4	(a)	(a)	72 000	27 500	44	50
136–7	1	400	72 500	35 000	33	49
136–15	7	400	71 000	32 500	37	50

a As received.

This material was not an extremely hard manganese bronze, and it is probable that in the case of brasses whose "work hardness" is much greater, such as No. 173, the elastic limit will be affected at lower temperatures than 400° C, and annealing even below that temperature will soften the material. It is, in fact,

possible that an inverse relation exists between the work hardness of the bronze and the temperature at which plastic flow begins under the influence of initial stress. However, this brass tested, No. 136, was as hard after annealing at 400° C as is ordinarily specified for manganese bronze and much harder than is required by the New York Board of Water Supply specifications, for instance.

It is interesting to notice that the stresses in the specimen 23 A were not so completely removed by annealing at 600° C for one-half hour as those in No. 136 by annealing for one hour at 300° to 400° C.
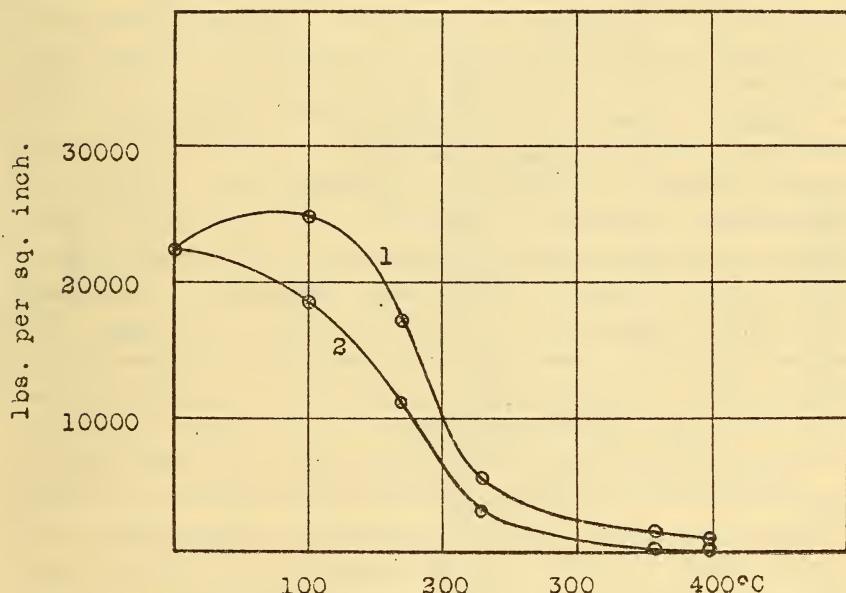
Fig. 11.—*Effect of annealing on the average initial stresses in a manganese bronze*

Abscissas	Annealing temperatures in °C
Ordinates	Average initial stress in pounds per square inch
Curve 1	For 1 hour's annealing
Curve 2	For 7 hours' annealing

It should here be emphasized that the results on the small 1-inch diameter rods, which were used in these annealing experiments, can not necessarily be taken as numerically characteristic also of heavier samples, for which higher temperatures and longer periods of heating are probably necessary in order to relieve the stresses.

In connection with the annealing of brass in order to relieve initial stresses, it may be mentioned that a whole filter in the city of Minneapolis filter plant was equipped with annealed plates and

bolts[25] and put in operation on February 15, 1915. To date, August, 1916, no breakages have been experienced in this filter, although the conditions are otherwise the same as those under which the failures described on pages 8–10 occurred. This experience indicates the practical effect of relieving the initial stresses in brass by annealing.

2. STRUCTURE OF BRASSES AND ITS RELATION TO FAILURES

In Fig. 12 is reproduced part of the equilibrium diagram for the copper-zinc alloys according to Carpenter.[26] Alloys containing up to about 37 per cent of zinc are homogeneous in structure and consist of the solid solution known as alpha. Alloys of compositions 37 and 47 per cent are heterogeneous and consist of mixtures of alpha and apparent beta, according to Carpenter, or beta prime, according to Hudson. Carpenter believes that the beta constituent breaks down into a eutectoid of alpha and gamma at 470° C, this eutectoid being in general of so fine a state of division that it appears as a homogeneous constituent. Hudson,[27] on the other hand, claims to have proven that the beta suffers merely an allotropic modification at 470° C, forming what he calls beta prime, a constituent which differs apparently in no sensible manner from beta. The authors will refer in general to the apparently homogeneous constituent which occurs together with alpha in 60:40 brasses as beta.

The tin-copper equilibrium diagram is quite similar to Carpenter's zinc-copper one, and the alloys show the same phase changes, except that there is a visible transformation of beta into a eutectoid of alpha and gamma. When tin is added to a copper alloy it dissolves in either or both of the solid solutions up to a certain extent and acts structurally very much like an addition of about 2.5 times that of zinc. For the sake of convenience one can then, from the structural standpoint, consider that a brass containing tin in not too large amounts is simply brass with a fictitious zinc content higher than its actual one by 2.5 times the content. If too much tin is added, depending upon the percentage of zinc present, a third constituent, the so-called delta constituent, appears.

Considering all such brasses, as Muntz metal, Naval brass, and Manganese bronze in this way, the shaded strip in the Fig. 12 represents the range of compositions (fictitious zinc compositions) usually met. For instance, a manganese bronze (copper, 56.89

[25] These were annealed for an hour or two at 700° C (1300° F) and cooled very slowly under lime.

[26] H. C. H. Carpenter, Further Experiments on the Critical Point at 470° C in Copper-Zinc Alloys; Journal of the Institute of Metals, **7,** p. 70; 1912.

[27] O. F. Hudson, The Critical Point at 460° C in Zinc-Copper Alloys, Journ. Inst. of Metals, **12,** p. 101; 1914.

per cent; zinc, 40.53 per cent; tin, 1.17 per cent) would be an alloy of $40.53 + (1.17 \times 2.5) =$ approximately 43 per cent fictitious zinc content.

The lead and the manganese usually found in these alloys (manganese only in manganese bronze) are present in very slight quantity and are generally dissolved in the two constituents, hence
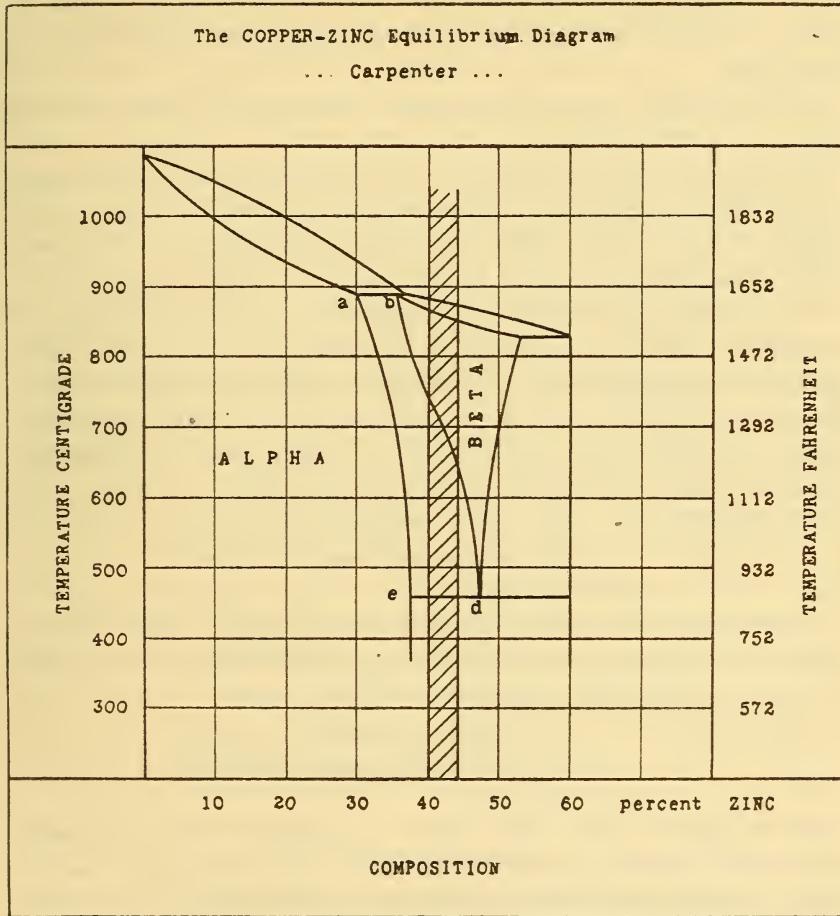
Fig. 12.—*Portion of the Cu-Zn equilibrium diagram according to Carpenter*
The shaded strip represents the range of compositions of brasses investigated

are not visible microscopically. The iron in manganese bronze may apparently either be dissolved in either alpha or beta or both, hence microscopically invisible, or it may be present as such in the form of fine globules.

It is then to be noticed that, in general, brass of this type should consist of beta grains inside of which the alpha has separated during cooling. If extensive work has been applied below the

line *bd*, of the separation of alpha, this constituent may be expected to show in its distribution the effects of that work.   In the case of rolled or drawn material, particularly if worked and annealed repeatedly, this distribution takes the form of parallel rows of elongated alpha and beta grains.

If, however, the work has been applied above the line *bd* the alpha constituent forms after the work has been done and hence shows no effect of this work, whereas the beta grains may be elongated.

Both of these types of structures are found in brasses of this type.

Of each of the specimens a three-fourths-inch longitudinal central section—that is, a center section parallel to the direction of rolling or axis of the rod—was prepared and etched.   This was taken immediately adjacent to the fracture in the case of the fractured specimens and taken so as to include one or more fissures in the case of the cracked or fissured materials.   These specimens were first heavily etched to show the macrostructure, and then repolished and lightly etched to show better the microstructure. Heavy etching of these alloys is best accomplished with an ammoniacal solution of copper-ammonium chloride:

Cu-Am-OH-(2)   5 gr. copper ammonium chloride
                      5 cc conc. ammonium hydroxide
                      120 cc water.

This reagent will develop nicely the beta grains, but for the purpose of developing the microstructure satisfactorily recourse may be had to a more dilute solution of (2) such as:

Cu-Am-OH-(1)   5 gr. copper ammonium chloride
                      7.5 cc conc. ammonium hydroxide
                      1000 cc water.

The reagent etches the alpha constituent dark in general. However, a queer fact was noticed in this connection, namely, that a specimen in which the alpha would etch dark at first would, after a period of several days, etch exactly in the reverse manner with the same reagent; that is, with alpha light.   The authors are inclined to look upon this phenomenon as being due to the release at the surface of initial stresses, which alter the relative corrodibility (electrolytic potential) of the beta and alpha constituents.

In some cases a light etch with ammonium hydroxide with hydrogen peroxide is more satisfactory, or a polish attack with ammonium hydroxide.   The latter etches beta dark in general.

A number of figures are given showing the typical macro- and microstructures of these brasses, and the Table No. 10 gives information concerning these. The direction of the axis of the rod or of the rolling or drawing operation is in all cases when not otherwise noted vertical on the page.

The Figs. 14 to 35 show the macrostructures of typical samples of brass. In most cases the beta grains can be seen, which vary greatly in size and are often elongated in the direction of rolling (see Figs. 25, 26, and 27). In other cases, Figs. 24, 29, 17, and 19, no traces of these grains can be noticed. In the case of specimen M-19, Fig. 16, the beta grains are fine elongated at the center and large polygonal at the edge. This illustrates the fact that recrystallization takes place more rapidly the greater the deformation undergone, which has been greatest at the surface in this case. This is the only case found of such a structure, except in the upset bolt heads, materials Nos. 60, 193, 197.

In the case of rivet head M-11, Fig. 15, the beta grains are surrounded by an alpha envelope; this material has been overheated in forging and is brittle, the fracture following the grain boundaries. Such intercrystalline fracturing or fissuring is very rare except in overheated material and was found only in these few cases of the rivet heads M 10 and 11 and in some brass plate M-131, which had been bent hot and evidently overheated in so doing. The fissures formed differed from ordinary season cracks in that they follow the crystal boundaries. This is shown in Fig. 96. A careful study was made of the structure at the fracture or near fissures in failed specimens in order to determine what the relation was, if any, between the structure and the fissure and to detect also traces of overheating. It was claimed, for instance, that the heads of the failed bolts from the Panama Canal had been burned. In no case, with the exception of specimens 10, 11, and 131, was the fracture intercrystalline. The fissures or line of fracture crossed the beta grains and the alpha particles indiscriminately, often changing direction somewhat as it passed from one beta grain to the next, but never seeking out the grain boundary. This is illustrated in Figs. 89 to 96. This fact is interesting in view of the fact that cracking of this type in alpha brasses, cartridge brass, etc., is almost universally intercrystalline.

With reference to overheating it was found that none of the specimens except the rivets 10 and 11 and possibly the plate 131 had been overheated. No traces of overheating were found in

the specimens from the Panama Canal. It should be pointed out in this connection that the term "burnt" applies only to metal which has been heated to incipient fusion, such that cohesion between the grains has been destroyed. The term is often used when "overheated" is meant.

Interesting are the macrostructures of the upset bolt heads, Figs. 20, 32, and 34, which show the effect of the work done on them in initial deformation of structure and in the recrystallization; the latter is more pronounced at top and sides than in the center, which is most probably accounted for by the fact that at these points greater deformation has been undergone by the material, which has therefore recrystallized here more rapidly.

The typical microstructures of the brasses are shown in Figs. 36 to 88. In many cases two are given for each specimen, one taken at the center and one at the edge (such that the center of the figure is 1 mm from the edge).

The two types of structure which were mentioned above are illustrated in Figs. 45–46, 36–37, and 69. These two types will be referred to as the linear and nonlinear structure, respectively. The former is found in naval brass, Muntz metal, and similar compositions, and but rarely in manganese bronze. An example of it in the latter material is seen in the case of material 197, Fig. 82. The structure of the manganese bronzes is generally nonlinear, as in Figs. 36, 37, 38, 39, 60, and 61. This varies from a more or less granular type (Fig. 42) to an oriented-alpha type (Figs. 36 and 37), with clearly defined beta grains.

The iron was, with the exception of No. 209, found as fine globules often arranged in rows parallel to the axis of the rod.

The Muntz metal and naval brass often showed in plain extruded form a nonlinear structure, illustrated in Figs. 48 and 69. In its extreme form this is shown in Fig. 96 of material No. 131, in which fracture was intercrystalline and characteristic of overheated material.

An interesting and rather unusual structure for commercial brasses is that of material No. 204, a naval brass, in which the so-called delta constituent [29] is visible. This is shown in Figs. 83 and 84 (light constituent). This constituent was very seldom found in the wrought brasses; it was apparently present also in No. 49, and possibly in No. 199.

In three cases the practically pure beta structure was found, in Nos. 209–A, 209–B, and 211. (See Fig. 86 of material No. 211.)

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[29] S. L. Hoyt, Trans. Amer. Inst. Metals; 1915.

An interesting type of structure (Fig. 87) is that of the threaded head of U-bolt 235, in which two generations of alpha are visible, the groundmass appearing much like a eutectoid.

Considering those materials which failed because of inherent defects, such as the presence of initial stresses or of incipient forging cracks, it can be stated that the structure alone does not indicate a latent tendency to crack or fail in this way. In particular, the presence of initial stresses is not indicated by the structure of these brasses. In alpha brass, on the other hand, the fact that a sample has received a large amount of cold work without a subsequent anneal, such that the initial stresses are high, may be detected by the presence of numerous "etch bands," as they have been called by Matthewson and Phillips [30] The structure of a sample of such a brass which season cracked is shown in Fig. 85.

One is accustomed, particularly in the case of pure metals, to associate a linear structure with initial stress, but the presence of such a structure in these brasses is, in fact, no criterion at all of the simultaneous presence of stresses, as may readily be seen by reference to the microstructure and data on initial stresses in the case of materials Nos. 83 and 161. Material No. 83 has a linear structure and very low stresses, whereas No. 161, with an open nonlinear structure, possesses very high stresses, and combinations of this sort are quite common.

Only one feature of structure has been found which is associated with failed and not with sound material, and that is the occurrence of large elongated beta grains, shown in Figs. 25 to 27. This structure has been found so far only in manganese-bronze lots which have failed, and seems to indicate a detail of manufacture, high temperature, or long period of heating above the diagram line *bd*, which is partially responsible at least for the presence of initial stress and tendency to season crack. Material having such a structure is certainly open to suspicion anyway, as one is inclined to associate large grain size and the oriented structure, which always goes with it, with brittleness, particularly to alternating stresses or impact. These materials having this structure do not, however, show brittleness in the tensile test, as will be seen by comparing the physical properties of materials Nos. 20, 158, 160, and 161, which possess this structure, to those of Nos. 136, 129, and 174, which possess a finer structure.

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[30] C. H. Matthewson and A. Phillips, The Recrystallization of Alpha Brass on Annealing, Trans. Amer. Inst. Mining Engrs., **52**, p. 1; 1916.

H. S. Primrose, in discussion,[31] assigns as a reason for brittleness in a manganese bronze, as shown by an elongation of only 8 per cent in 2 inches, the oriented structure of the material, which resembles that of material No. 158. As this latter material has, however, an elongation of 31 per cent, one can not evidently definitely relate brittleness with this structure.

It may be remarked that there is some reason to believe that the presence of the globules of iron in such materials renders them more sensitive to forging operations, and the presence of such particles may be assigned as a contributory factor in the failure of upset boltheads such as those of the Panama Canal. Bolt No. 247 was particularly rich in such particles. (See Fig. 88.)

The variation in structure from edge to center was studied from the standpoint of obtaining an indication of the variation in work done on the material from edge to center, which might be related to the value of the initial stresses. But in material No. 85, possessing very small stresses, there is a great variation in this structure (Figs. 47 and 48), whereas in No. 160 (Figs. 60 and 61), possessing large stresses, the variation is insignificant.

Unquestionably an indication could be obtained of the magnitude of the initial stress through the structure if only one material were used and a definite and uniform method of manufacture were followed, but with so many variables in the situation it must be admitted that the structure can not be utilized directly for this purpose.

3. SOME CORROSION AND ACCELERATION TEST

The Heyn test with mercurous nitrate was carried out on several of the materials. This test is by many considered to give a fair criterion of whether a material will season crack, as it has been found that most brasses which season crack will crack within a short time in this solution. In these tests the brass specimens were immersed for four hours at ordinary temperature in a solution containing 65 gr. of $HgNO_3$ and 15 cc conc. HNO_3 per liter. The specimens were of necessity short in most cases; that is, only 2 inches long.

Specimens

3*	40	83	103	121	140	158*	[a] 164	169*
21	54	85	109	124	142	160*	165	[a] 170
33	57	92	116	129	153	161	166	171*
34	67	94	118	131	156	162	167*	[a] 172
38	75	101	120	136*	157	163	[a] 168	173*
								[a] 174

[a] 10-inch specimens were also so tested, and gave the same behavior as the 2-inch ones.

[31] Journ. Inst. Metal, **12**, p. 53; 1914.

FIG. 13.—*Material No. 169 after immersion in water for two weeks*

Within this time (and afterwards) only the specimens marked with an asterisk, Nos. 3, 136, 158, 160, 167, 169, 171, and 173, cracked or showed any sign of fissure. Nos. 158 and 160 contained, after the test, transverse cracks only, No. 171 one longitudinal crack, and the others both. These cracks appeared generally in less than five minutes. From this it appears that only those materials crack under the mercurous-nitrate acceleration test which have at the surface tensional stresses above a certain value, which may provisionally be set at 30 000 pounds per square inch for the type of materials tested. Materials having compression stresses at the surface, even when these are large (No. 164 had 32 000 pounds per square inch compression at the surface), are not affected in this test.

Furthermore, three specimens, Nos. 140, 142, and 118, having large tensional stresses at the surface, did not fail under this test. As these were typical of material which failed, one must conclude that this test is not a sufficient one; material which fails under the test should not be accepted, but not all defective materials fail under this test. Results similar to the above were found with some few tests with ammonium hydroxide, which seems to act in the same way.

It was desired to ascertain what action water alone would have on samples of these materials. A 6 or 8 inch sample of specimens 136, 164, and 167 to 175 was immersed in a large water tank at the Bureau on May 8 and allowed to remain for about four weeks. It may be recalled that material No. 167 is the same as 168, similarly 169 and 170, 171 and 172, and 173 and 174, the only difference between the two samples of the same material in each of the four cases being that the samples with odd numbers, Nos. 167, 169, 171, and 173, were drawn very hard, whereas the others were given a comparatively light draw to size only, most of the work of forming having been done by extrusion. The stresses in the former group are large and the surface is in tension, whereas in the latter the stresses are small and the surface is in compression. No external stress was applied; nevertheless, during this time Nos. 169 and 171 developed longitudinal cracks, and No. 167 both longitudinal and transverse ones. Fig. 13 shows the specimen 169. The other samples were not affected by this treatment (No. 173 was lost and no data is available on its behavior during this test).

These tests are interesting, first, as indicating what a slight impetus is necessary to cause failure in a material which is already

in a high initial stress, since the surface corrosion which took place in this time was insignificant. The specimens were merely tarnished. During that time specimens of the same materials lying in the shop did not crack.

4. HARDNESS VALUES

The cause of the presence of initial stress is, as indicated above, to be sought either in the variation of the rate of cooling of different parts of the article, or in the differing degree to which different parts were deformed or worked, either hot or cold. It is to be expected that the properties of the material in the differently treated layers would be different, and Heyn[32] has shown that this is true of the density, the elastic limit, and possibly also of the ultimate strength and elongation in the tensile test. The density, for instance, is greater in the outer layer of a cold-drawn aluminum bronze bar than in the center ones.

Determinations were made of the Brinell hardness of several samples of the brasses investigated in order to ascertain what relation, if any, existed between the amount of initial stress and the amount of variation of hardness from center to edge of these materials. Transversely cut specimens were taken and one impression made at the center and one or more at about 3 mm from the edge, and the hardness numeral calculated in each case. The results of these tests are given in Table 3.

It is seen from the table that there is no reliable concordance between the hardness values or their variations and the values of the initial stresses. In general, the greater the initial stress the greater is the variation from edge to center of the hardness numeral, the latter being greater at the edge (except in one case, that of No. 205). But very definite exceptions to this relation are noted. The hardness variation for specimens of low initial stress is from 1 to 2 points, whereas that for several specimens of high initial stress is from 5 to 10 points. Yet No. 205, a specimen of low stresses, is softer by about 8 points at the center than at the edge; No. 161, of high stresses, has a difference of only about 2 points in the value of the hardness numeral; and specimens 163 and 186, of low initial stresses, have variations of from 8 to 9 points in this value. Furthermore the Muntz metal 171–172, as finished hard, No. 171, shows no variation from center to edge of the hardness, whereas the same material, No. 172, finished softer, has a variation of 14 points.

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[32] Loc. cit.

One is forced to conclude that there exists no possiblity of obtaining a reliable indication of the presence of initial stresses in a material through the study of the hardness numeral, nor consequently of the liability of such a material to season crack.

5. DISCUSSION OF RESULTS

In attempting to relate the occurrence of failures among lots of brass with the properties, etc., of the materials one is confronted by the fact of the simultaneous variation of two main factors—for example, the service stresses and the initial stresses. It is, however, possible to divide the materials which have been in service roughly into three classes, according to the severity of the service stresses.

(1) Certain of the samples, comprising mostly drawn material, had season cracked in storage and before the application of any service stress whatever. These were Nos. 1 to 3, 7, 8, 9, 78, 131, 160, 161, 167,[33] 169,[33] and 211. The fissures were transverse—that is, to axis of bar or rod—in Nos. 3, 7, 8, 9, 78, 160, and 161; longitudinal in No. 2, spiral in Nos. 167 and 169; and they took the form of square checker work inclined 45° to the axis of the bar in No. 211, as shown in Fig. 3. Reference to Table 5 shows that, where measured, these specimens, with the exception of No. 131, had tensional stresses in the outer layer varying from 26 000 to 83 000 pounds per square inch. In all cases in which the proportional limit of these materials was known the stress value in the outer layer was greater than the proportional limit. Furthermore, in each of these cases the average stress was high, representing a large amount of energy tending to rupture the bar. Failure in these cases was undoubtedly due primarily to the presence of initial stress, and these materials must be considered defective.

In the case of No. 131 the outer layer was in severe compression parallel to the cracks and to the flange bend and in tension at right angles to the cracks; this tension stress was low in value such that the initial stresses as measured can not be considered responsible for failure. The cracks occurred in the areas which had been bent by "heating a part of the plate in a forge and bending it over a cast-iron form, then heating and bending another piece, and so on, until the whole circumference was flanged." This subsequent forging operation is in all probability responsible for failure in this case; it is probable that during the rapid and

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[33] These cracked while lying in the Bureau shops.

unequal cooling of the flanged part initial stresses were introduced which are not susceptible of measurement in the usual way. Such local stresses might be set up as a consequence of unequal coefficients of thermal expansion of the alpha and the beta constituents, and might readily be of a nature and magnitude sufficient to start these cracks.

(2) The second class comprises those articles, mostly bolts, which failed in service under moderate service stresses—that is, easily within the proportional limit of the material. These are Nos. 69 to 77, 107 to 117, 125, 126, 134, 137 to 139, 140 to 144, 151, 152, 158, 159, 209, 235, and 247. Of these Nos. 107 to 117 and 137 to 139 may have been subjected to service stresses as high as 15 000 pounds per square inch; the others to stresses of lesser value. Nos. 69 to 77, 107 to 117, 140 to 144, 158 and 159 possessed initial stresses of high average values ranging from 9000 to 30 000 pounds per square inch. Nos. 74 and 116 showed compressional stress in the outer layer, whereas the others had in this layer high tensional stress. There is thus no difficulty in accounting for the cracking in the case of Nos. 140 to 144, 158 and 159. The hook bolts, 107 to 117, all failed at the bend, and it is therefore probable that it was to a high initial bending stress that failure was due. The cracks always started from the concave side of the bend and Howard [34] has shown that this side of a brass bar bent cold is always in tension. These stresses unfortunately could not be measured. No. 74, representing Nos. 69 to 77, presents the interesting case of a bolt which fractured in service under moderate load and in which there is a large initial compressive stress in the outer layers amounting to from 10 000 to 20 000 pounds per square inch. It is impossible to say whether failure started at the surface or not; no bolts have been found, however, showing cracks growing in from the surface, and it is therefore possible that fracture started at the center of the bolt (as in a transverse-fissured rail), where the initial tensional stress amounted to about 16 000 pounds per square inch. This would be contrary, it may be noted, to the fact generally observed that cracking of this type extends inward from the surface.

The initial stresses in No. 125 could be measured only in a direction parallel to the fissures, and in this direction but moderate stresses were found. The authors believe that the stresses in a direction at right angles to this would be much more severe and in a reverse distribution; that is, with tension at the surface.

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[34] *Loc cit.*

Thus it is believed that the presence of initial stresses was also in these cases a predominating factor in causing cracking, and these materials must also be looked upon as defective in the sense of possessing too high initial stresses.

The other articles of this class had all received a subsequent heat treatment or forging operation, sometimes local in character; the cracks always appeared in those areas so treated, such that it is not to be expected that the initial stresses as measured often outside of these areas will bear any relation to the failure. This is in fact true. The stresses when measured were found to be low, and it is to a consideration of the operations performed on the material subsequent to the passing of the material out of the manufacturer's hands to which one must turn in quest of explanation of the failure.

The bolts 137 to 139 were heated to about 600° C and quenched in water. The plate 209 had been flanged cold and afterwards annealed; the structure showed, however, that the two failed specimens, 209–B and 209–C, had been thereupon cooled very rapidly, perhaps quenched, whereas the sample which had not failed gave no structural indication of such severe treatment. Tests made by cooling samples of 209–C at different rates from about 750° C, and observing the structure showed that 209–A and 209–B had been cooled more rapidly than can be done in a blast of cold air, presumably, therefore, quenched in water.

Now one of the authors in connection with some other work had occasion to quench a 1-inch diameter rod of an alloy, such as that of 209, from about 650° to 700° C in order to retain the pure beta structure. This was found literally cracked to pieces after such treatment, such that it could be almost crumbled in the hand. This indicates how sensitive such a material is to drastic treatment of this kind.

Concerning No. 138, in which only slight stresses were measured, it is believed that there may exist local stresses not susceptible of measurement in the usual way, set up during the rapid cooling of the heterogeneous alloy, due to a difference in the coefficient of expansion of the constituents alpha and beta. Some preliminary measurements of these coefficients made by D. H. Sweet and L. W. Schad, of this Bureau, would tend to bear out this view.

The fracture in the manganese-bronze bolts, 235 and 247, from the Panama Canal, occurred within areas forged or upset, namely,

at a forge bend and in the upset threaded head of 235 and at the base of the head (upset) in 247, and are undoubtedly caused by some improperly executed detail of this operation. Fracture occurred in both cases through cross sections of greater area than adjacent ones under the same total stress, but which had not been affected by the forging operation.

One can assume that local and hence not readily determinable initial stresses were set up during forging, which were unrelieved and finally caused failure. But there is also another and very plausible explanation; that is, that invisible internal cracks were formed during forging, which opened up when a service stress was applied. That such cracks are formed is a fact well known to manufacturers of manganese bronze, and it is also known that these materials have temperature zones in which they are quite brittle, and if work is done on them at these temperatures, the ductility is readily exhausted and cracks will appear. These may be so fine as to be almost invisible; they often do not extend to the surface, but make known their presence only when a stress is applied which then opens them up.

Bengough[35] says, concerning the ductility of his "complex" brass, which is somewhat similar to manganese bronze: "At high temperatures the ductility of bars of this alloy can not be satisfactorily measured, owing to the fact that numerous wide cracks opened up in the bar. * * * This phenomenon was also observed at all temperatures above 400° C, and at 700° C rendered elongation measurements useless." He found a diminution of ductility in this alloy in the neighborhood of 500° C.

The fractured end of bolt 247 showed a second transverse crack about ⅜ inch back of the fracture. This material also contained perhaps the largest proportion of iron present as separate globules, undissolved, that the authors have yet seen. Large particles of such iron were also found during the machining of specimens, which totally ruined the tool. Such particles of iron would tend to promote the formation of such forging cracks.

In these latter cases the fault can not be put upon the material, but more justly to the operation of forging, done perhaps by persons inexperienced in the handling of this material. As an illustration of this it is noted that the firm Q which carried out the flanging work on No. 131 are machinists and founders, manufacturing sugar-refining machinery, and the rivets 10, 11, 132, "were

[35] G. D. Bengough, A Study of the Properties of Alloys at High Temperatures, Journal of the Institute of Metals, **7**, p. 123; 1912.

driven by an experienced *boiler maker*." There is no doubt of the danger of entrusting such work to men experienced only in steel working.

(3) The third class comprises several lots of manganese-bronze bolts, used in making up flange joints, in which there is some doubt as to the magnitude of the service stress introduced by drawing the bolts up tight. The opinion is expressed by the engineers familiar with the work that all of the stud bolts 20 to 39, 40 to 48, and 189 to 192, and many of the hexagon head bolts 49 to 68 and 193 to 194, were drawn up above the elastic limit of the material, an approximate estimate of 15 000 pounds per square inch having been assigned to this stress. Most unfortunately, from the stand-point of attempting to draw conclusions from the investigation of these bolts, this opinion is not borne out in the case at least of Nos. 20 to 39 by a study of the initial stresses in the bolts which have failed.

When such a bolt containing high initial stresses is stretched as a bolt above the elastic limit of the material, the value of the initial stresses must be diminished—the initial stress diagram flattened out; upon applying, for example, a tensional stress of 40 000 pounds per square inch (the value of the proportional limit) to the specimen 164, the center portion will be under a stress of about 53 000 pounds per square inch and must yield, whereas the outer portions will be in tension varying from 30 000 to 10 000 pounds per square inch and can not yield. Thus upon removing the applied stress the difference between the maximum tension and the maximum compression, taken algebraically, must be less by about 13 000 pounds than originally. This was actually done in the case of specimen 164. After removal of the stress of 40 000 pounds per square inch the average stress had fallen from 12 000 pounds per square inch to about 5000 pounds per square inch. There is the possibility that in these thick, short bolts the bolting stress may itself have been very nonuniform, the load having been carried mostly at the periphery. In that case such a distribution of stresses as has been found in such bolts might have been preserved or even intensified upon drawing up above the elastic limit.

Bolts, lot 20 to 39 and lot 189 to 192, were similar and had been subjected to the same service. Eighty-three per cent of the first lot failed, none of the second. The initial stresses were high, about 15 000 pounds per square inch in average value in the first lot and low, about 7700 pounds per square inch, in the second. The fissures started from the surface at the base of the thread and ex-

tended inward, although the outer layers were in initial compression, amounting at the base of the thread to 15 000 pounds per square inch in the case of No. 32.   None of bolts 40 to 48 had failed, although about 16 per cent of the lot which they represent did. The average stresses are low, 4000 to 5000 pounds per square inch in these specimens.

The only hexagon-head bolt, lot 49 to 68, which failed in the body of the bolt, not immediately adjacent to the forged head, was No. 67, and in this case the outer layer was under an initial tension of 12 000 pounds per square inch.   The other bolts of this lot showed low initial stresses and the fracture took place at the base of the thread or at the shoulder of the head.   In the former cases one must assume that the service overstress was responsible for failure, whereas in the latter, since the cross-sectional areas at the fracture were greater than at sections through the threaded portion of the bolt, one may conclude again that the forging of the heads was not correctly done.

A great deal of material has been examined which has not failed, although it has nevertheless been in service under varying severe conditions.   Such materials as have been indicated above do not differ markedly or consistently in their physical properties or structure from that which has failed.   The initial stresses are, however, in general, found to be lower in magnitude than in the case of the latter.   As instances of such material may be cited Nos. 41 and 43, 181 to 183, 184, 185 to 188, 189 to 192, 193 to 200, 244, and 245.   Of these, Nos. 184, 244, and 245 have been subjected to small service stresses; Nos. 181 to 183, 185 to 188, and 193 to 200 to moderate service stresses; and Nos. 40 to 48 and 189 to 193 to severe service stresses.   The average of the average initial stress in these samples is something less than 5000 pounds per square inch.

Furthermore, the experience on the Minneapolis filter plant with bolts and strainer plate, which have been thoroughly annealed, and thus relieved of initial stresses, is of the greatest value, since under the identical service conditions under which 20 per cent of the similar, but unannealed, materials failed within 30 days, after over one year, now absolutely no breakages have occurred.

The next question that arises is that of the manner in which such failures as have been described may be prevented.   It has been seen that there are several factors which may cause failure

of the general type in question, and for each of these factors a separate safeguard is needed.

A number of failures have resulted from improper forging operations and heat treatment undertaken by persons not wholly familiar with the properties of the material. This has occurred mainly with manganese bronze (with the exception of some naval brass plate, rivets, and bolts). There has resulted from the forging of good material, in most cases, either a highly stressed condition within the forged area, or fine internal cracks have been formed which have afterwards opened up under stress. The obvious remedy for this is to intrust such operations only to men familiar with this material and its extreme sensitiveness to forging operations at certain temperatures.

A number of failures have occurred in satisfactory material (bolts) as a result of overstressing in service. This opens up at once a large field for investigation into the question as to what are the safe working stresses for various 60:40 brasses and just how much they will stand abuse of the sort that does not apparently harm steel. This is a question, the answer to which must be reserved for future work to present; work has already been started along this line at this Bureau. Ernst Jonson [36] has already given a valuable contribution to the solution of this question in his work on the failure of brasses exposed to the action of concentrated ammonium hydroxide while under stress. He comes to the conclusion that any brass, irrespective of initial-stress distribution, will fail in this way when the stress value is kept for a few days or weeks at or just above the elastic (or proportional) limit, and his results, including tests made on an initial-stress free sample, No. 136, annealed, and on one with large compressional stress at the surface, No. 164, amply bear out his conslusion. He then carries this conclusion over to actual service conditions in which corrosion is by air and water instead of by ammonia, and states that again the true elastic limit is the highest stress which such a material will stand in tension, accompanied by corrosion. The authors have in mind failures which have occurred in burned-in and other castings, which would lead them to agree with this conclusion also; but only a full investigation can definitely decide this point, and not until such investigation has been made can the designing engineer know definitely what he may expect of such materials. Until then it would seem that the history of materials such as 40 to 48, 181 to 200, 244 to

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[36] Loc. cit.

245, and that of the annealed bolts of the Minneapolis filtration plant would give assurance that, provided the material is free from initial stresses, these materials can be designed with entire safety to carry loads of about 5000 pounds per square inch, possibly even 10 000 pounds per square inch, provided the true elastic limit is definitely above this value.

Finally, a large percentage of the failures described were due wholly or in part to the presence of initial stress as measured. These stresses are introduced by those processes which give a brass article "work-hardness," and manufacturers claim that when one obtains such highly stressed material it is generally the result of an attempt on the buyer's part to set the physical specifications for tensile strength and yield point too high, with the result that the specification can only be met with initially highly stressed material.

The question of safeguarding oneself against obtaining such defective material is a manifold one. One can most easily obtain stress-free material by specifying that it receive a sufficient final anneal (one hour at from 400° to 550° C). By such treatment the initial stresses are almost wholly removed, and when a high value for the elastic limit is not required this is the only rational method to use. Indeed, if the annealing be done at not above 400° C, the material may still possess a high elastic limit as was shown in IIe. If this be not done, or in case assurance is wanted that it has been done, recourse must be taken to a direct measurement of the initial stresses as described above. The question then arises, what are the limiting safe values for initial stresses? To such a question no general reply can be given; the values of the initial stresses, which may be allowed in such materials, are dependent in any particular case upon external conditions and the physical properties of the materials. The authors are of the opinion (1) that it is dangerous to use any brass in which the tensional stress at the surface is nearly equal to the elastic limit; (2) that failure may occur whenever the sum of the initial stress and the load stress in any layer is greater than the elastic limit of the material of that layer, particularly in the surface layer. Assuming then a case in which an average manganese bronze is used, with a proportional limit of from 15 000 to 20 000 pounds per square inch and in which the service stresses, accompanied by moderate corrosion, amount to from 5000 to 10 000 pounds per square inch, and bearing in mind that the average initial stress is the value most readily measured, one may conclude that an average initial stress value of 5000 pounds

per square inch is a safe one; with this value no layer would, except with unusual initial stress distribution, be subjected to a tensional stress above its proportional limit.

This value probably errs on the safe side; it is probable that under certain circumstances higher stresses might be allowed without danger. It agrees, however, very well with those average values in materials, which have been in service and have not failed (under all but overload stresses), and may, it is believed, safely be accepted as a conservative upper average initial stress limit.

This value also appears to agree well with the experience of manufacturers. The latter appear to have, generally speaking, a pretty definite knowledge of the upper limit of physical properties (ultimate strength and elastic limit) to which they may go with safety with their various materials, and beyond which the material is in danger of season cracking when exposed to corrosion. Now, in many cases, as indicated above, manufacturers were requested to furnish material possessing the greatest hardness which, in their opinion and experience, was still consistent with freedom from danger from season cracking. Samples which were sent in answer to this request, and which represent, as far as physical and other properties are concerned, what might be called the optimum manufacturing practice in these brasses, are Nos. 203 and 205.[37]

Materials Nos. 165, 166, 168, 170, 172, and 174 were sent in answer to a request for samples of material such as the manufacturer would furnish for his highest specification contracts. This request involves, although less directly, the same idea, namely, that this material is supposed to be the hardest that the manufacturer recommends in consideration of the danger from cracking. It is now noted that, with two exceptions, Nos. 165 and 166, both from the same manufacturer, the values of the average initial stresses in these brasses are lower than 6000 pounds per square inch, and range approximately from 3000 to 6000 pounds per square inch. This concordance seems to be an independent corroboration of the authors' results, which is based upon the large experience of the producers of brass themselves, and gives this value a somewhat more general significance.

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[37] The manufacturer specifically stated in regard to these materials that in his opinion the latter possessed the highest ultimate strength and elastic limit in tension (for this type of material as manufactured by him) which were consistent with safety.

TABLE 8

Correlation of Tensile Strength and Average Initial Stress in Manganese Bronze 1 Inch Rods [a]

B. S. No.	Ultimate tensile strength		Chemical analysis				Average initial stress	
			Copper	Zinc	Tin	Iron		
	lbs./in.²	kg./cm.²	Per cent	Per cent	Per cent	Per cent	lbs./in.²	kg./cm.²
173............	100 000	7030	57	40	1.6	1.3	37 000	2600
205............	84 000	5920	59	40	.4	1.0	5000	350
174............	84 000	5920	57	40	1.6	1.2	3000	210
129............	79 000	5560	59	39	.9	1.0	15 000	1050
175............	77 000	5420	57	41	1.0	.6	6000	420
136............	72 000	5070	59	39	.8	.7	22 000	1550
3...............	70 000	4940	60	39	.8	.5	25 000	1760
160............	61 000	4300	57	41	.9	1.0	30 000	2110
189............	62 000	4360	57	41	1.0	1.5	8000	560
b...............	72 000	5070	58	40	.7	.7	5000	350

[a] Round numbers are given here for the sake of convenience in comparing values.
[b] This data is an average of a lot including Nos. 49, 50, 54, 63, 67, and 68.

TABLE 9

Physical Properties and Initial Stresses in the Best Brasses Tested [a]

B. S. No.	Initial stress				Physical properties in tension						Kind of material
	Average		Maximum		Ultimate strength		Proportional limit		Elongation in 2 inches	Reduction of area	
	lbs./in.²	kg/cm²	lbs./in.²	kg/cm²	lbs./in.²	kg/cm²	lbs./in.²	kg/cm²	P. ct.	P. ct.	
174.......	3000	210	9000	630	84 000	5910	36 000	2530	22	20	Manganese bronze.
205.......	5000	350	9000	630	85 000	5980	52 000	3660	22	41	Do.
175.......	6000	420	9000	630	77 000	5420	26 000	1830	27	27	Do.
85........	1000	70	2000	140	61 000	4290	16 000	1120	47	51	Naval brass.
170.......	7000	490	12 000	840	68 000	4800	43 000	3020	31	47	Do.
203.......	5000	350	9000	630	71 000	5000	44 000	3100	31	57	Do.
164.......	12 000	840	33 000	2320	72 000	5060	40 000	2810	16	50	Muntz metal.
172.......	4000	280	11 000	770	64 000	4500	36 000	2540	40	50	Do.

[a] Values are given in round numbers.

It was hoped that the tests made of these various materials, particularly those furnished directly by the manufacturers, would bring out some rough parallelism between initial stresses and hardness for a given material, such a relation as would give some indication as to what properties one might reasonably demand of such materials. This has not been true, however; no such relation can be deduced, as is clearly shown from Table 8. All that can be done is to draw attention to certain examples as indicating what is possible.

It is apparently possible to obtain commercially physical properties, including hardness, in all of these materials sufficient to meet not only the New York Board of Water Supply specifications, but many others given in the Appendix, page 63, and in conjunction with low values of the initial stress. An idea of what may be obtained in these materials can be had from Tables 8 and 9.

One wonders, after consideration of specimens 205 and 175, with elastic limits of 52 000 and 76 000 pounds per square inch and average initial stresses of 5000 and 6000 pounds per square inch, respectively, why a specimen, such as 160 of the same material, with an elastic limit of only 14 000 pounds per square inch should have an average initial stress of 30 000 pounds per square inch. It is evident that the low values of the hardness and of the ultimate strength and elastic limit in tension give no assurance that the material is not at the same time highly initially stressed.

III. CONCLUSION

1. The results of the investigation have thus far shown that the failures occurring in the construction of the Catskill Aqueduct, in the Minneapolis Filtration Plant, and on the Panama Canal, in wrought-brass materials of the type 60:40, have been due (a) to the presence of initial stresses, either alone or in conjunction with external load; (b) to faulty practice in forging bolt heads, flanging plate, etc.; and (c) to overstress in service caused by drawing bolts up too tightly. These failures were thus partly due to defects in material, but must be ascribed in part to service abuse.

2. These materials, speaking broadly, should, when sound and comparatively free from initial stresses, support service stresses of 5000, or perhaps even up to 10 000 pounds per square inch without failing. If, however, there are present also initial stresses, there may be said to exist the possibility of cracking whenever the sum of the service tensional stress and the initial tensional stress in any layer, but particularly the outer layer exposed to corrosion, is greater than the proportional or elastic limit of the material in that layer. If, in the extreme case, the initial tensional stress in the outer layer is, itself, greater than the elastic limit, failure will take place before the application of any external stress; that is, the material will season crack.

3. There is thus no definite value which may be assigned as a safe limit for initial stresses in such materials, for each case must be a law unto itself. However, assuming the average grade of material and the ordinary service stresses (tension) of about 5000 pounds per square inch, a value of 5000 pounds per square inch may be

assigned as a conservative limit for the allowable average initial stress; this refers particularly of course to rods. This value accords well (*a*) with such stress values found in materials which have given good service, and (*b*) with stress values found in rods furnished by manufacturers as representing the hardest material which could be guaranteed against cracking.

4. One-inch diameter rods of various 60:40 mixtures manufactured to meet high physical specifications have contained average initial stresses averaging about 5000 to 6000 pounds per square inch.

5. Too few samples have been investigated to allow of any definite conclusion as to how high specifications may be set for these materials, without undergoing danger that the product obtained may be too highly initially stressed. It seems, however, that it is possible to obtain ultimate strengths of 70 000 to 75 000 pounds per square inch for a manganese bronze, those of 65 000 to 70 000 pounds per square inch for naval brass, and from 60 000 to 65 000 pounds per square inch in Muntz metal, associated with initial stresses of sufficiently moderate value. Just how much higher one may go consistently is a question that can not yet be decided; that these materials can, with perhaps special treatment, be made with much higher ultimate strength is shown. It may be noted that the values given are not to be accepted necessarily as normal ones; i. e., to be specified by the engineer. In setting specifications the leeway necessary to the manufacturer must not be neglected.

6. The surest convenient method of ascertaining the approximate average value of the initial stresses in bars is by the Howard-Heyn elongation method, in which a strain gage may be used and heavy layers removed.

WASHINGTON, July 7, 1916.

Appendix.—SPECIFICATIONS FOR WROUGHT BRASS

1. U. S. NAVY SPECIFICATIONS

(a) MANGANESE BRONZE (46B15, APR. 1, 1914)

MANGANESE BRONZE, ROLLED, OR COMPOSITION Mn-r

General Instructions

1. General Instructions or Specifications issued by the Bureau concerned shall form part of these specifications.

Scrap

2. Scrap shall not be used in the manufacture, except such as may accumulate in the manufacturers' plant from material of the same composition of their own make.

Chemical and Physical Requirements

3. The chemical and physical requirements shall be as follows:

Diameter	Mini-mum tensile strength	Mini-mum yield point	Mini-mum of elonga-tion in 2 inches	Copper	Tin	Zinc	Iron	Lead (maxi-mum)	Man-ganese (maxi-mum)
	lbs./in.²	lbs. in.²	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1 inch and below...	72 000	36 000	30	57–60	0. 5–1. 5	40–37	0. 8–2. 0	0. 2	0. 3
Above 1 inch........	70 000	35 000							

4. The material must not contain more than 0.1 of 1 per cent of all elements in addition to those allowed in the table above.

Additional Tests

5. Bars must stand: (a) Being hammered hot to a fine point; (b) being bent cold through an angle of 120° and to a radius equal to the diameter or thickness of the test bar.

The bending test bar may be the full-size bar, or the standard bar of 1 inch width and one-half inch thickness. In the case of bending test pieces of rectangular section, the edges may be rounded off to a radius equal to one-fourth of the thickness.

Surface Inspection

6. Material must be free from cracks and all other injurious defects, clean, smooth, and must lie straight. All bars to be clean and straight, of uniform quality, size, and color. * * *

Fracture

8. The color of the fracture section of test pieces and the grain of the material must be uniform throughout.

Purposes For Which Used

9. Rolled round rods requiring great strength where subject to corrosion and salt water—

Valves stems, etc.

Propeller blade bolts, air pump and condenser bolts, and parts requiring strength and incorrodibility.

(*b*) **NAVAL BRASS (46B6b, MAY 1, 1915)**

ROLLED NAVAL BRASS, OR COMPOSITION N-r, BARS, SHAPES, SHEETS, PLATES, AND RODS

General Instructions

1. General Specifications for the Inspection of Material, issued by the Navy Department, in effect at date of opening of bids, shall form part of these specifications.

Scrap

2. Scrap will not be used in the manufacture, except such as may accumulate in the manufacturers' plants from material of the same composition of their own make.

Chemical and Physical Properties

3. The chemical and physical requirements shall be as follows:

Copper	Tin	Zinc	Iron, maximum	Lead, maximum
Per cent 59–63	Per cent 0.15–1.5	Per cent Rem.	Per cent 0.06	Per cent 0.2

	Minimum tensile strength	Minimum yield point	Minimum elongation in 2 inches	Bend, 120° cold
Rods (diameter):	lbs./in.^{3}	lbs./in.^{2}	Per cent	
0 to ½ inch............................	60 000	27 000	35	Radius equals thick-
Over ½ to 1 inch........................	58 000	26 000	40	ness.
Over 1 inch.............................	54 000	25 000	40	
Shapes: All...............................	60 000	27 000	30	Do.
Plates:				
0 to ½ inch up to 30 inches width........	56 000	28 000	30	Do.
0 to ½ inch above 30 inches width.......	54 000	27 000	35	Do.
Over ½ inch thick.......................	56 000	26 000	35	Do.

Test Pieces

4. Test pieces for rounds and bars will be as nearly as possible of the same diameter as the rounds, or else they are not to be less than one-half inch diameter and taken at a distance from the circumference equal to one-half the radius of the rounds.

Test pieces from plates and shapes will be of the 2-inch standard size specified as given in the "General Specifications for Inspection of Material."

Bending test bar may be the full-size bar or the standard bar of 1 inch width and ½ inch thickness. In the case of bending test pieces of rectangular section the edges may be rounded off to a radius equal to one-fourth of the thickness.

Surface Inspection

5. Material must be free from all injurious defects, clean, straight, smooth, must lie flat, be of uniform color, quality, and size, and be within the gauge and weight tolerances. * * *

Proprietary Materials

8. Various composition materials, otherwise conforming to the specifications but manufactured under proprietary processes or having proprietary names, may be submitted in bids for consideration of the bureau concerned.

Tolerances

9. No excess weight will be paid for and no single piece that weighs more than 5 per cent above the calculated weight will be accepted.

Underweight and Gauge Tolerances (Width of Sheets or Plates)

	Under 48 inches	48 to 60 inches	Over 60 inches
Tolerance..	5 per cent.	7 per cent.	8 per cent.

Plates and sheets shall not vary throughout their length or width more than the given tolerance.

Fracture
10. The color of the fracture section of test pieces and the grain of the material must be uniform throughout.

Purposes For Which Used
11. The material is suitable for the following purpose, especially if subject to corrosion as by salt water: Bolts, studs, nuts, and turnbuckles; rolled rounds, used principally for propeller blade bolts, air pump and condenser bolts and parts requiring strength and incorrodibility, and pump rods, tube sheets, supporting plates, and shafts for valves in water heads.

2. NEW YORK BOARD OF WATER SUPPLY

The following specifications were used just previous to the discovery of cracking in a large amount of the brasses:

(a) The minimum physical properties of bronze shall, except as otherwise specified, be as follows:

Castings:
      Ultimate tensile strength....................... 65 000 pounds per square inch,
      Yield point................................... 32 000 pounds per square inch,
      Elongation................................... 25 per cent.
Rolled material, thickness 1 inch and below:
      Ultimate strength............................ 72 000 pounds per square inch,
      Yield point................................... 36 000 pounds per square inch,
      Elongation................................... 28 per cent.
Rolled material, thickness above 1 inch:
      Ultimate strength............................ 70 000 pounds per square inch,
      Yield point................................... 35 000 pounds per square inch,
      Elongation................................... 28 per cent.

After being forged into a bar, rolled or forged bronze shall stand first, hammering hot to a fine point; second, bending cold through an angle of 120° to a radius equal to the thickness of the bar. * * *

Tensile strength of brass rivet rods shall be not less than 55 000 pounds per square inch.

Yield point not less than 30 000 pounds per square inch.

Elongation not less than 20 per cent.

The following specifications were used after the discovery of cracking (1914):

(b) Whenever the characteristics of any bronze or other material are not particularly specified, such approved material shall be used as is customary in first-class work of the nature for which the material is employed.

59850—17——5

The minimum physical properties of bronze shall, except as otherwise specified, be as follows:

Castings:
    Ultimate tensile strength...................... 65 000 pounds per square inch,
    Yield point................................... 32 000 pounds per square inch,
    Elongation................................... 25 per cent.
Forgings:
    Ultimate tensile strength...................... 70 000 pounds per square inch,
    Yield point................................... 35 000 pounds per square inch,
    Elongation................................... 28 per cent.
Hot-rolled or extruded bronze:
    Ultimate tensile strength...................... 68 000 pounds per square inch,
    Yield point................................... 27 000 pounds per square inch,
    Elongation................................... 30 per cent.

Tensile strength of brass rivet rods shall be not less than 50 000 pounds per square inch.

Yield point not less than 20 000 pounds per square inch.

Elongation not less than 32 per cent.

After being forged into a bar, rolled, forged or extruded bronze shall stand, first, hammering to a fine point; second, bending cold through an angle of 120° to a radius equal to the thickness of the bar, without showing signs of fracture.

All forged, extruded, or rolled bronze shall be subjected to test with a scleroscope, and if hardness is found materially exceeding that typical of hot-worked metal, the bronze shall be rejected or annealed promptly, as directed.

The present general specifications for brass (1915) are as follows:

Composition by Percentage

	Copper	Tin	Iron	Lead	Zinc
Muntz metal.............................	59–62	....	....	0.6 max.	Rem.
Naval brass.............................	59–62	0.5–1.25	....	.2 max.	Rem.
Manganese bronze.......................	57–61	.5–1.25	0.5–2.0	.2 max.	Rem.

Minimum Physical Requirements for Hot-Rolled, Extruded, and Annealed Material

	Yield point	Ultimate strength	Elonga- tion
	lbs./in.^{2}	lbs./in.^{2}	Per cent
Muntz metal...	20 000	50 000	32
Naval brass...	22 000	56 000	32
Manganese bronze...	27 000	68 000	32

Drawn Material Not Annealed

Muntz metal...	25 000	50 000	25
Naval brass...	30 000	60 000	25
Manganese bronze...	35 000	70 000	25

For sheets and tubing the required minimum elongation shall be 5 per cent less than given in the table. All material shall stand being bent cold through an angle of 120° and to a radius equal to its diameter or thickness. Bars shall stand being hammered

hot to a fine point.   Scrap shall not be used in the manufacture except such as comes from the same composition made in the same mill.   The material shall be free from all injurious defects, and shall be clean, smooth, and straight and of uniform quality and size.   Unless otherwise specially permitted, all bars shall be extruded or hot rolled and not subsequently drawn or cold rolled.   The straightening of hot-worked material shall be done by simple bending, not accompanied by compression between two opposite rolls.   Plates shall be hot rolled, except that sheets less than one-fourth inch may be cold rolled and annealed.   All hot-rolled material shall be tested with the scleroscope, and if the hardness is found to exceed materially that typical of hot-worked metal the rods shall be annealed.

Drawn and unannealed material shall be tested for initial strain.   In case of material one-fourth inch or more in thickness this test shall be made by measurement.   When so tested the maximum strain shall not exceed 0.002 inch in a length of 4 inches.   The test specimen shall be 5¾ inches long.

After the length has been measured the test specimen shall be cut down for a length of 4 inches, as follows: Bars shall be turned to one-third of the original diameter. Flats shall be machined to one-third the original width and thickness and plates and tubing to one-third the original thickness.   The length shall then again be measured. The difference between the two measurements shall be regarded as the maximum initial strain.

Bars shall be measured at three marked equidistant points on the circumference; flats and plates at two points, one at each edge.   Test pieces of plates shall be 2 inches in width.   Each measurement shall be the average of five observations at each measuring point.   In testing tubing the entire section shall be used, one-third of the thickness being turned off on the outside and one-third bored out on the inside.   Sheets and tubing less than one-fourth inch in thickness shall be tested by immersion in a saturated solution of mercuric chloride for one hour, and then kept under observation for two weeks.   If cracks appear during this test, the initial strain shall be regarded as excessive.   When doubt exists the specimen shall be slightly bent to open cracks.   Test pieces subjected to this test shall be 5¾ inches long and 2 inches wide.

3. SPECIFICATIONS OF THE ENGINEER'S DEPARTMENT OF THE CITY OF MINNEAPOLIS FOR BRASS BOLTS AND STRAINER PLATE

SPECIFICATION NO. 1

Extracts from Specifications for Strainer Plates for Repairs to Filters, City of Minneapolis, Minn.

*   *   *   *   *   *   *

Sec. 3. Quality

All strainer plates shall be made of Tobin bronze No. 14, Birmingham wire gage, having a tensile strength of at least 62 000 pounds per square inch and an elongation of not less than 25 per cent in 8 inches, with an elastic limit of at least one-half the ultimate tensile strength.   When cold, the sheets must be capable of being bent 180° flat on themselves without fracture on the outside of bent portion.   All strainer holes shall be $\frac{3}{32}$ inch in diameter and shall be drilled or punched before the plates are bent to the required shape.   The plates shall butt at their ends and sides, and therefore must be smooth and true on all edges.   All plates must be so made or cut as to give the greatest strength in a longitudinal direction.   All hook bolts and ribs must be made of Tobin bronze, meeting the same requirements as to physical properties as above mentioned for the plates.   The ⅝-inch round anchor rods may be made of a good quality of brass, phosphor bronze or Tobin bronze, the latter being preferred.

Sec. 4. Damaged Material

Should any piece of the above material become damaged in any way either in handling or shipment in transit or before, it will be rejected and shall be removed from the work and another piece substituted immediately at the expense of the contractor.

Sec. 5. Guarantee

The contractor shall guarantee all material to be as specified and each piece of Tobin bronze must be marked "Tobin bronze" with the name of the firm manufacturing the same, the letters to be at least $\frac{1}{8}$ inch in height and plainly stamped in the metal. Failure to do this will be sufficient reasons for rejection.

Sec. 6. Rejection

An inspector, appointed by the city engineer, may, under instructions and directions from the city engineer, inspect and supervise the work and material at the shop and see that the stipulations of the plans and specifications are faithfully performed. Tests shall be made under his personal supervision wherever he so requires, and the contractor shall furnish him with all the proper tools, specimens, appliances, and labor necessary. The passing of such inspection shall not release the contractor from his contract, and the material may be rejected at any subsequent period if found defective in any way. * * *

<div align="center">

SPECIFICATION NO. 2

EXTRACTS FROM SPECIFICATIONS FOR STRAINER PLATES FOR NEW FILTERS, MINNEAPOLIS, MINN., 1914

*   *   *   *   *   *   *

</div>

Sec. 2. Workmanship and Materials

The workmanship must be first class in all respects, and the materials the best of their respective kinds, and if at any time any piece of work is deemed by the city engineer or his lawful representative to be defective it shall be removed from the work immediately and be replaced by one acceptable to the city engineer. The cost of doing so must be borne by the contractor with no additional expense to the city.

Sec. 3. Quality

All strainer plates shall be made of Tobin bronze No. 14, Birmingham wire gage, having a tensile strength of at least 62 000 pounds per square inch and an elongation of not less than 25 per cent in 8 inches, with an elastic limit of at least one-half the ultimate tensile strength. When cold, the sheets must be capable of being bent 180° flat on themselves without fracture on the outside of bent portion. All strainer holes shall be $\frac{3}{32}$ inch in diameter and shall be drilled or punched before the plates are bent to the required shape. The plates shall butt on their ends and sides, and therefore must be smooth and true on all edges. All plates must be so made or cut as to give the greatest strength in a longitudinal direction. All anchor bolts and ribs must be made of Tobin bronze, except as hereinafter provided. The anchor bolts must meet the same requirements as to physical properties as above mentioned for the plates. The ribs may be cast and when so made must be capable of withstanding a unit tensile stress of at least 42 000 pounds per square inch without fracture. The $\frac{5}{8}$-inch round anchor rods may be made of a good quality of brass, phosphor bronze or Tobin bronze, the latter being preferred. All cast-iron base plates must be made from the best quality of gray pig iron, cough and even grained, and shall possess a tensile strength of at least 20 000 pounds per square inch. Specimen test bars of the cast iron used, each 26 inches long by 2 inches wide and 1 inch thick, shall be made without charge as often as the engineer may direct, and in default of definite instructions the contractor shall make and test at least one bar from each heat or run

of metal. The bars when placed flatwise on supports 24 inches apart and loaded at the center shall support a load of 2200 pounds and show a deflection of not less than 0.35 of an inch before breaking, or, if preferred, tensile bars shall be made which will show a breaking point of not less than 20 000 pounds per square inch. Bars to be cast as nearly as possible to the dimensions without finishing, but corrections may be made by the engineer for variation in width and thickness, and the corrected result must conform to above requirements.

Sec. 4. Defects in Castings

Castings must be clean and perfect without blow or sand holes or defects of any kind. No plugging or other stopping of holes will be allowed.

Sec. 5. Connecting Rods

The contractor shall furnish all connection rods for the base plates as per plans accompanying these specifications. All connecting rods shall be made from the best quality of double-refined iron or steel and the threads are to be standard tap-bolt threads to fit the taps in the base-plate castings, one end being threaded left and the other right-hand thread.

Sec. 6. Damaged Material

Should any piece of the above material become damaged in any way either in handling or shipment in transit or before, it will be rejected and shall be removed rom the work and another piece substituted immediately at the expense of the contractor.

Sec. 7. Guarantee

The contractor shall guarantee all material to be as specified and each piece of Tobin bronze must be marked "Tobin bronze" with the name of the firm manufacturing the same, the letters to be at least ⅛ inch in height and plainly stamped in the metal. Failure to do this will be sufficient reasons for rejection.

Sec. 8. Rejection

An inspector, appointed by the city engineer, may, under instructions and directions from the city engineer, inspect and supervise the work and material at the shop and see that the stipulations of the plans and specifications are faithfully performed. Tests shall be made under his personal supervision wherever he so requires, and the contractor shall furnish him with all the proper tools, specimens, appliances, and labor necessary. The passing of such inspection shall not release the contractor from his contract, and the material may be rejected at any subsequent period if found defective in any way. * * *

PHOTOGRAPHS AND PHOTOMICROGRAPHS

TABLE 10

Photographs and Photomicrographs

Fig. No.	B. S. specimen	Magnified	Etching	Position of area photographed	Fig. No.	B. S. specimen	Magnified	Etching	Position of area photographed
14......	3	2	Cu-Am-OH-2.		56......	156	50	Cu-Am-OH-1.	Center.
15......	11	2	Cu-Am-OH-2.		57......	158	50	Cu-Am-OH-1.	Do.
16......	19	2	Cu-Am-OH-2.		58......	159	50	Cu-Am-OH-1.	Edge.
17......	28	2	Cu-Am-OH-2.		59......	159	50	Cu-Am-OH-1.	Center.
18......	41	2	Cu-Am-OH-2.		60......	160	50	Cu-Am-OH-1.	Edge.
19......	50	2	Cu-Am-OH-2.		61......	160	50	Cu-Am-OH-1.	Center.
20......	60	1½	Cu-Am-OH-2.		62......	161	50	Cu-Am-OH-1.	Edge.
21......	94	2	Cu-Am-OH-2.		63......	161	50	Cu-Am-OH-1.	Center.
22......	109	4	Cu-Am-OH-2.		64......	166	50	Cu-Am-OH-1.	Edge.
23......	134	2	Cu-Am-OH-2.		65......	166	50	Cu-Am-OH-1.	Center.
24......	136	2	Cu-Am-OH-2.		66......	167	50	Cu-Am-OH-1.	Edge.
25......	158	2	Cu-Am-OH-2.		67......	167	50	Cu-Am-OH-1.	Center.
26......	159	2	Cu-Am-OH-2.		68......	168	50	Cu-Am-OH-1.	Do.
27......	161	2	Cu-Am-OH-2.		69......	172	50	Cu-Am-OH-1.	Do.
28......	172	2	Cu-Am-OH-2.		70......	175	50	Cu-Am-OH-1.	Do.
29......	185	2	Cu-Am-OH-2.		71......	181	50	Cu-Am-OH-1.	Edge.
30......	187	2	Cu-Am-OH-2.		72......	181	50	Cu-Am-OH-1.	Center.
31......	189	1	Cu-Am-OH-2.		73......	184	50	Cu-Am-OH-1.	Edge.
32......	193	1	Cu-Am-OH-2.		74......	184	50	Cu-Am-OH-1.	Center.
33......	195	2	Cu-Am-OH-2.		75......	187	50	Cu-Am-OH-1.	Edge.
34......	197	1	Cu-Am-OH-2.		76......	187	50	Cu-Am-OH-1.	Center.
35......	204	2	Cu-Am-OH-2.		77......	189	25	Cu-Am-OH-1.	Edge.
36......	22	50	Cu-Am-OH-1.	Edge.	78......	189	25	Cu-Am-OH-1.	Center.
37......	22	50	Cu-Am-OH-1.	Center.	79......	193	25	Cu-Am-OH-1.	Do.
38......	34	50	Cu-Am-OH-1.	Edge.	80......	195	50	Cu-Am-OH-1.	Edge.
39......	34	50	Cu-Am-OH-1.	Center.	81......	195	50	Cu-Am-OH-1.	Center.
40......	41	50	Cu-Am-OH-1.	Edge.	82......	197	25	Cu-Am-OH-1.	Do.
41......	41	50	Cu-Am-OH-1.	Center.	83......	204	50	Cu-Am-OH-1.	Do.
42......	49	50	Cu-Am-OH-1.	Do.	84......	204	1000	Cu-Am-OH-1.	
43......	67	50	Cu-Am-OH-1.	Do.	85......	201A	400	NH₄OH+H₂O₂	
44......	78	50	Cu-Am-OH-1.	Do.	86......	211	25	NH₄OH+H₂O₂	At fissure.
45......	83	50	Cu-Am-OH-1.	Edge.	87......	235	100	NH₄OH+H₂O₂	Head.
46......	83	50	Cu-Am-OH-1.	Center.	88......	247	100	NH₄OH+H₂O₂	At fissure.
47......	85	50	Cu-Am-OH-1.	Edge.	89......	31	35	Cu-Am-OH-1.	
48......	85	50	Cu-Am-OH-1.	Center.	90......	34	20	Cu-Am-OH-2.	
49......	116	50	Cu-Am-OH-1.	Edge.	91......	38	35	Cu-Am-OH-1.	
50......	125	50	Cu-Am-OH-1.	Center.	92......	47	20	Cu-Am-OH-1.	
51......	129	50	Cu-Am-OH-1.	Edge.	93......	78	50	Cu-Am-OH-1.	
52......	129	50	Cu-Am-OH-1.	Center.	94......	112	20	Cu-Am-OH-1.	
53......	136	50	Cu-Am-OH-1.	Edge.	95......	138	20	Cu-Am-OH-1.	
54......	136	50	Cu-Am-OH-1.	Center.	96......	131	20	Cu-Am-OH-1.	
55......	140	50	Cu-Am-OH-1.	Do.					

INITIAL STRESS DIAGRAMS

TABLE 11

List of Initial Stress Diagrams

Fig. No.	Material	Remarks	Fig. No.	Material	Remarks
97.......	3	As received.	109.......	214–1	As received, turned down.
98.......	32	Do.	110.......	214–2	As received, bored out.
99.......	43	Do.	111.......	157	Do.
100.......	67	Do.	112.......	160	As received.
101.......	74	Do.	113.......	164	Do.
102.......	92	Do.	114.......	167	Do.
103.......	136–2	Do.	115.......	168	Do.
104.......	136–24	Do.	116.......	173	Do.
105.......	136–50	2½-inch specimen.	117.......	174	Do.
106.......	136–51	10-inch specimen.	118.......	182	Do.
107.......	136–a	Bored out.	119.......	199	Do.
108.......	136–6	Annealed one hour at 400° C.	120.......	204	Do.

NOTE.—In all of the initial stress diagrams are plotted as abscissas, diameters squared in square inches, as ordinates initial fiber stresses in pounds per square inch.
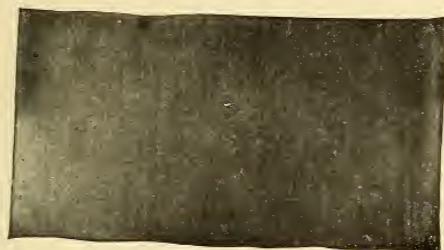
FIG. 14

Material 3 × 2
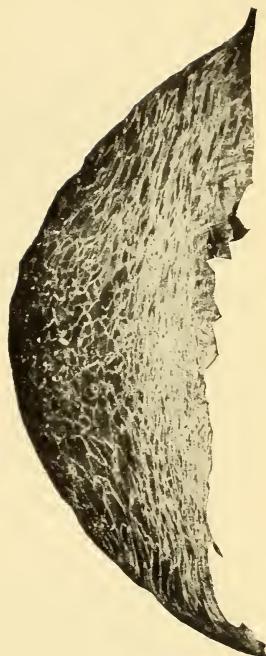
FIG. 15

Material 11 × 2

FIG. 16

Material 19 × 2
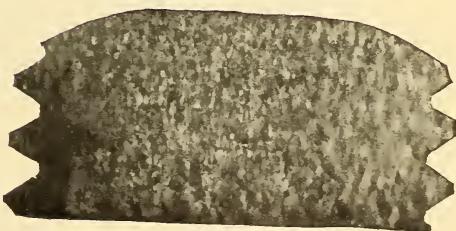
FIG. 17

Material 28 × 2

FIG. 18
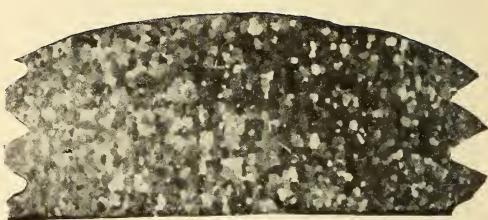
Material 41 × 2

FIG. 19

Material 50 × 2
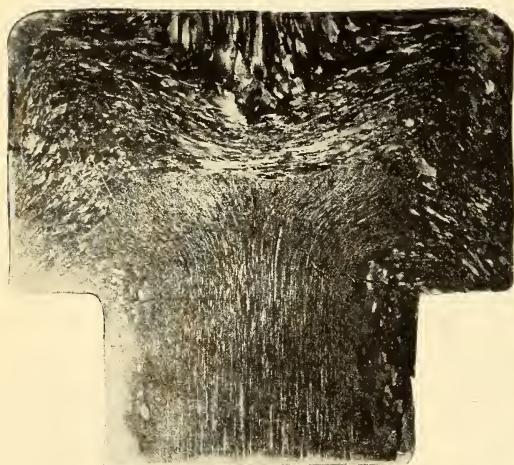
FIG. 20

Material 60 × 1.5
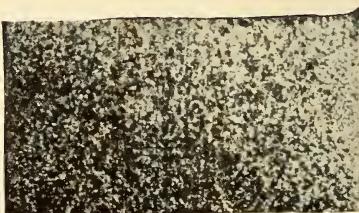
FIG. 21

Material 94 × 2
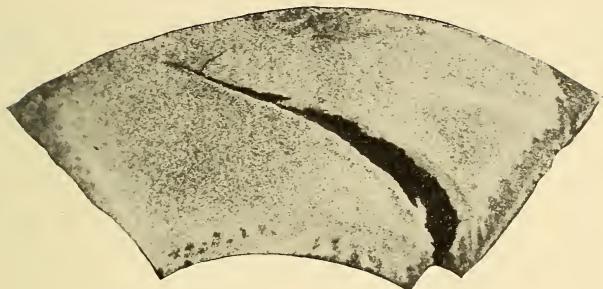
FIG. 22

Material 109 × 4

FIG. 23

Material 134 × 2
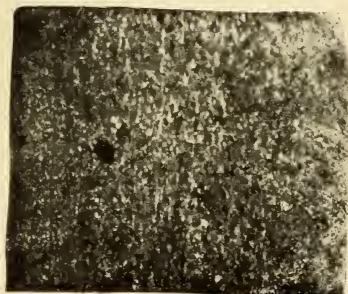
FIG. 24

Material 136 × 2

FIG. 25

Material 158 × 2

FIG. 26
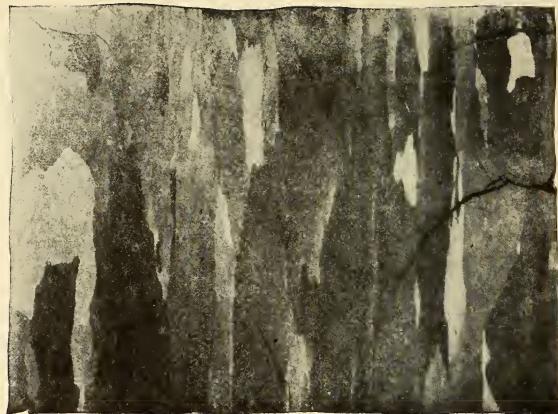
Material 159 × 2

FIG. 27

Material 161 × 2
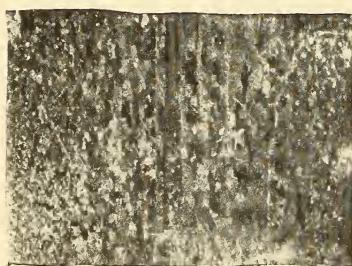
FIG. 28

Material 172 × 2
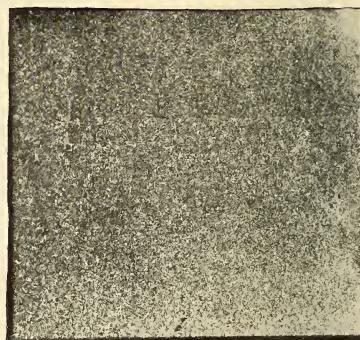
FIG. 29

Material 185 × 2
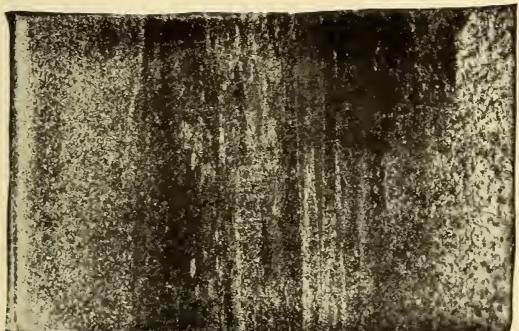
FIG. 30

Material 187 × 2
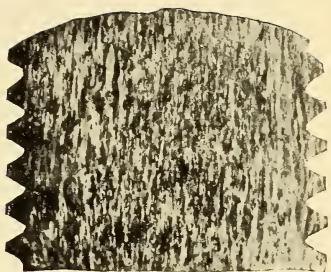
FIG. 31

Material 189 × 1
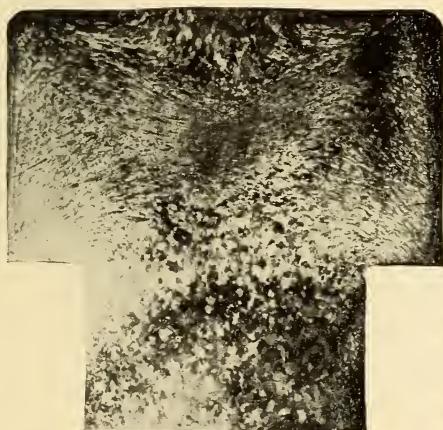
FIG. 32

Material 193 × 1
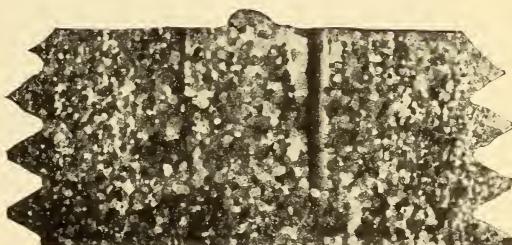
FIG. 33

Material 195 × 2

Fig. 34

Material 197 × 1

Fig. 35

Material 204 × 2
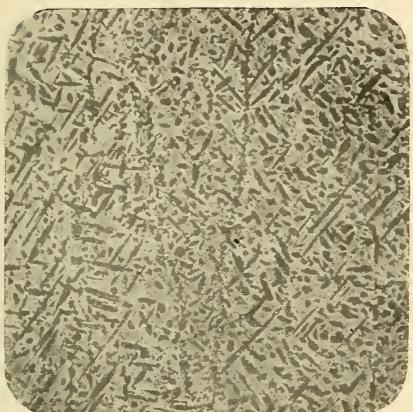
FIG. 36

Material 22 (edge) × 50
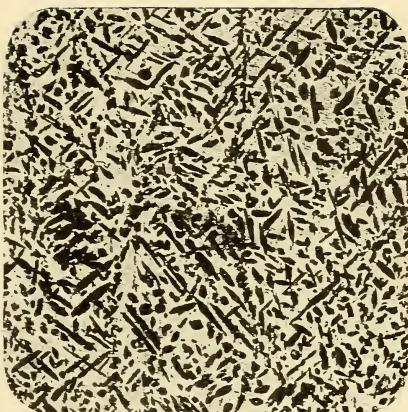
FIG. 37

Material 22 (center) × 50
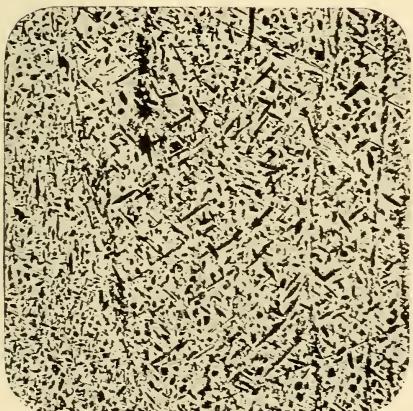
FIG. 38

Material 34 (edge) × 50
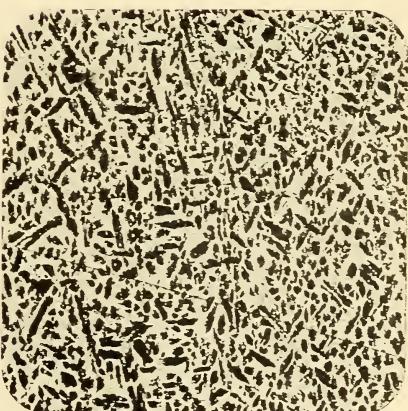
FIG. 39

Material 34 (center) × 50
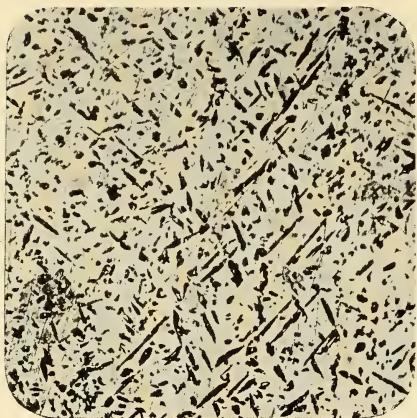
FIG. 40

Material 41 (edge) × 50
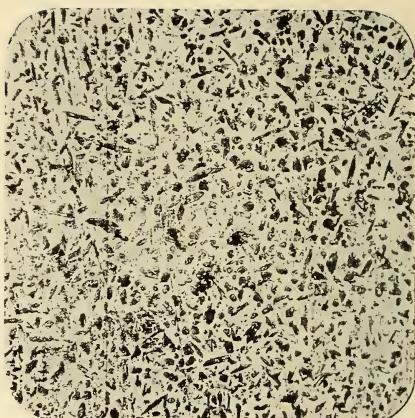
FIG. 41

Material 41 (center) × 50
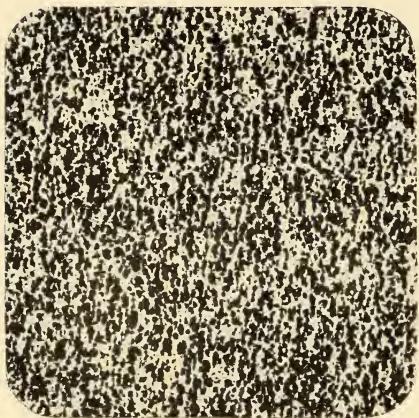
FIG. 42

Material 49 (center) × 50
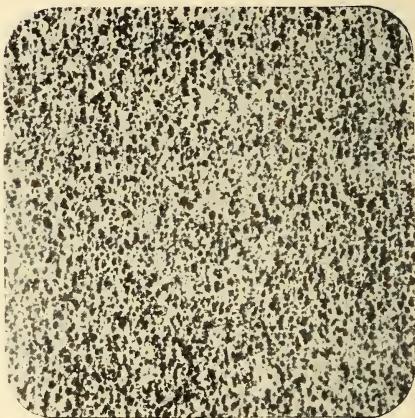
FIG. 43

Material 67 (center) × 50
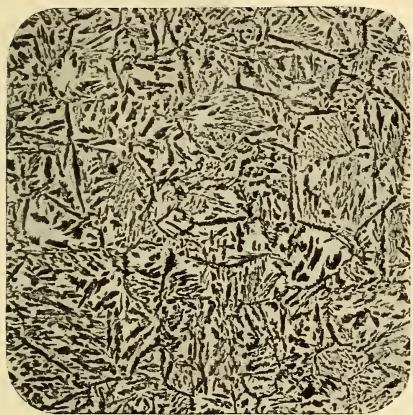
FIG. 44

Material 78 (center) × 50
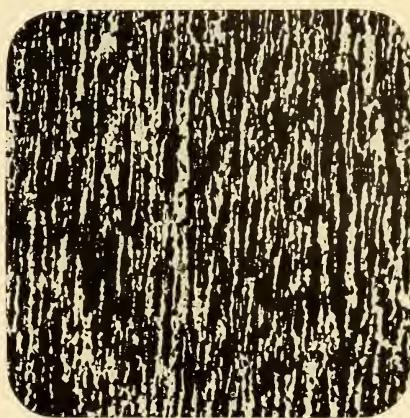
FIG. 45

Material 83 (edge) × 50
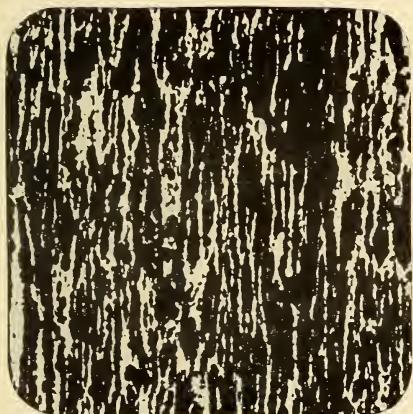
FIG. 46

Material 83 (center) × 50
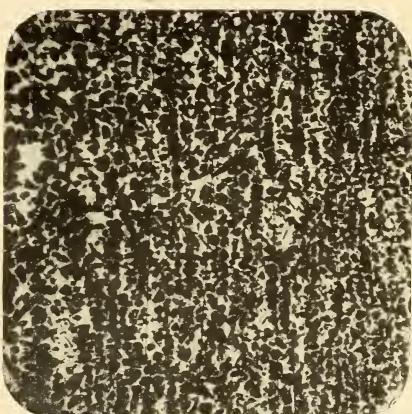
FIG. 47

Material 85 (edge) × 50
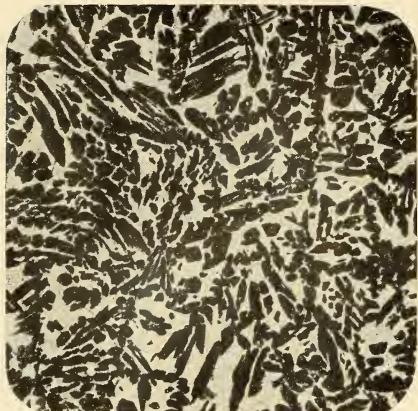
FIG. 48

Material 85 (center) × 50
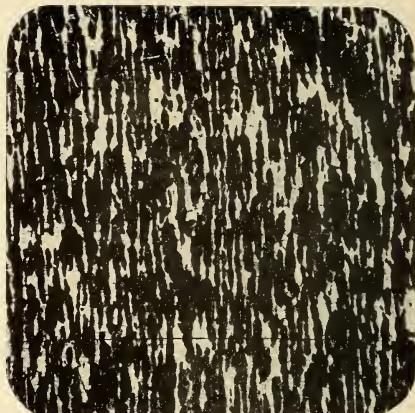
FIG. 49

Material 116 (edge) × 50
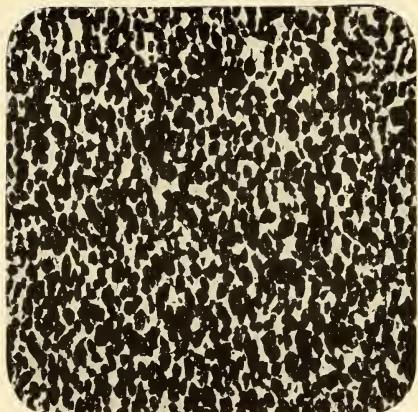
FIG. 50

Material 125 (center) × 50
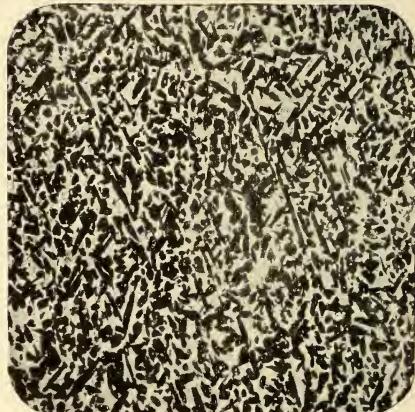
FIG. 51

Material 129 (edge) × 50
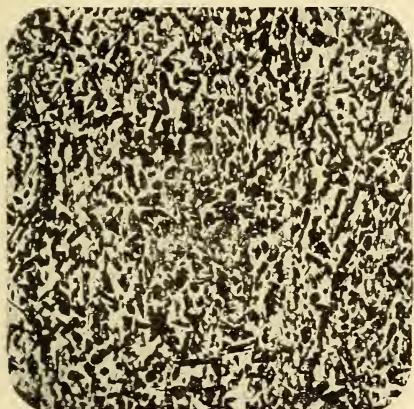
FIG. 52

Material 129 (center) × 50
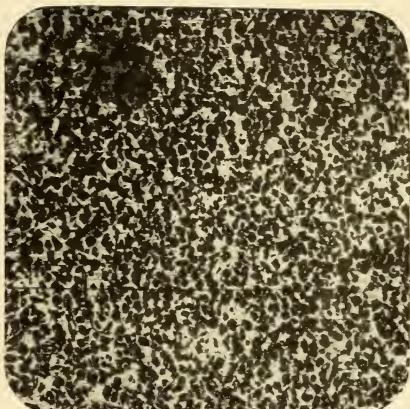
FIG. 53

Material 136 (edge) × 50
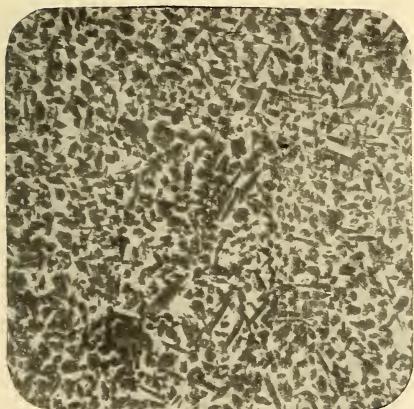
FIG. 54

Material 136 (center) × 50
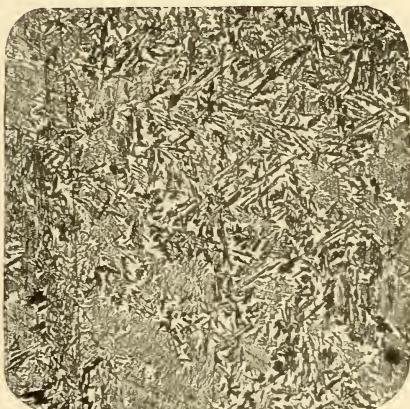
FIG. 55

Material 140 (center) × 50
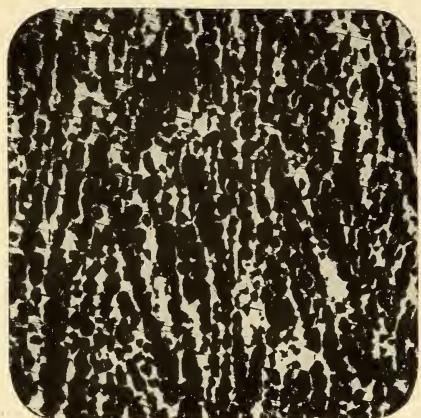
FIG. 56

Material 156 (center)   × 50
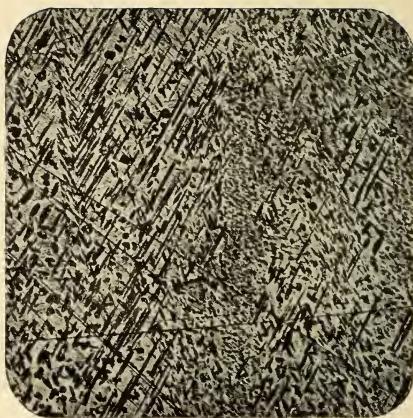
FIG. 57

Material 158 (center)   × 50
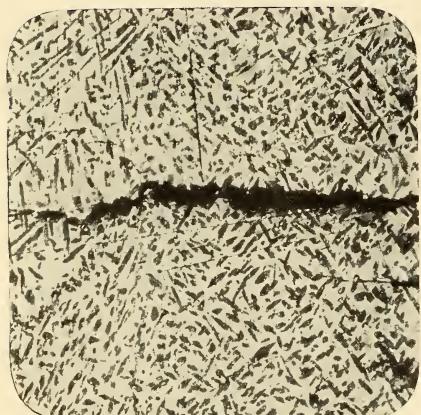
FIG. 58

Material 159 (edge)   × 50
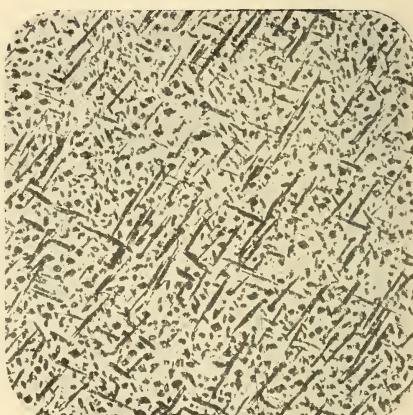
FIG. 59

Material 159 (center)   × 50
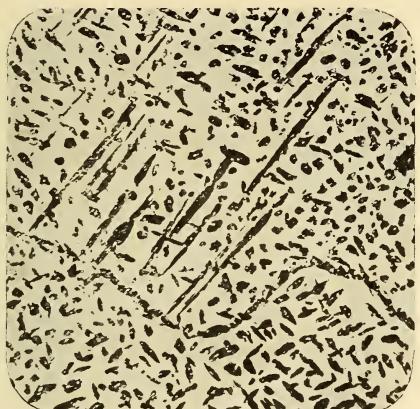
FIG. 60

Material 160 (edge) × 50
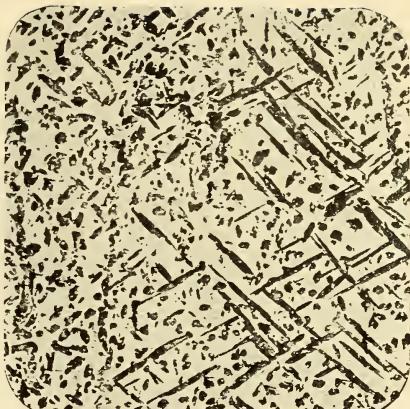
FIG. 61

Material 160 (center) × 50
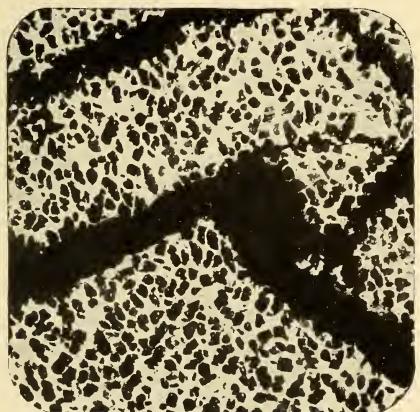
FIG. 62

Material 161 (edge) × 50
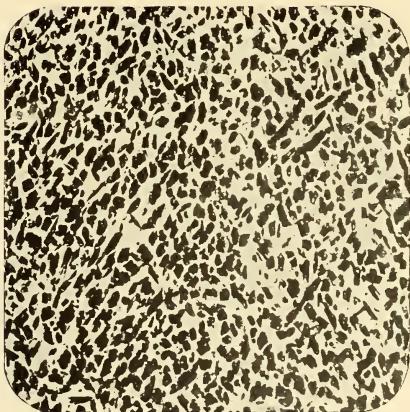
FIG. 63

Material 161 (center) × 50

FIG. 64

Material 166 (edge) × 50
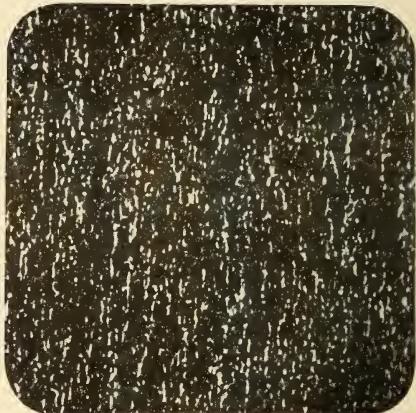
FIG. 65

Material 166 (center) × 50
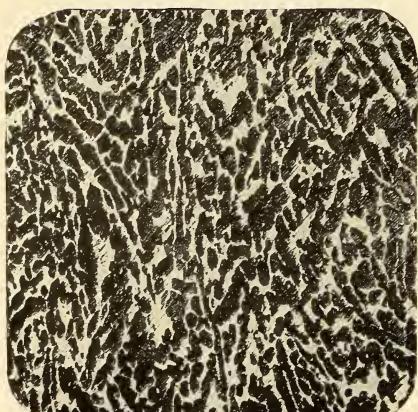
FIG. 66

Material 167 (edge) × 50
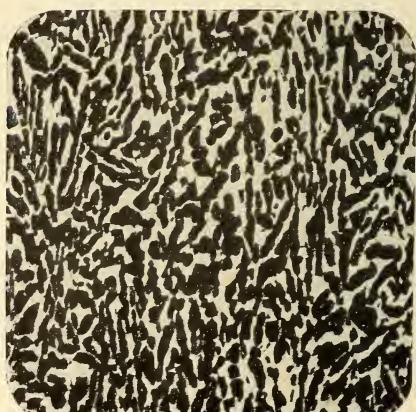
FIG. 67

Material 167 (center) × 50
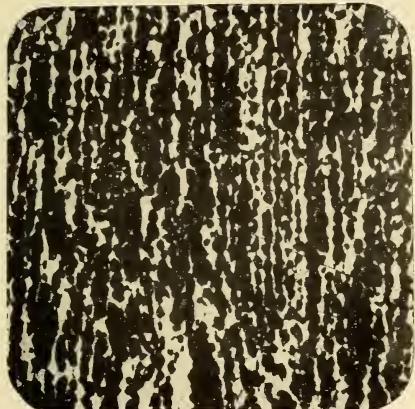
FIG. 68

Material 168 (center) × 50
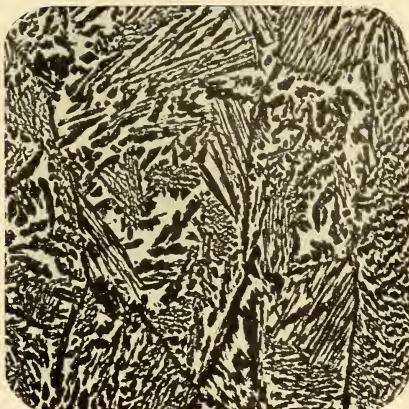
FIG. 69

Material 172 (center) × 50
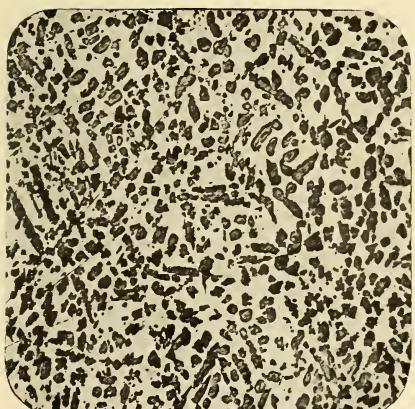
FIG. 70

Material 175 (center) × 50
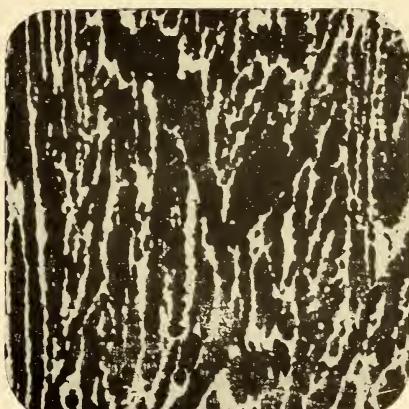
FIG. 71

Material 181 (edge) × 50
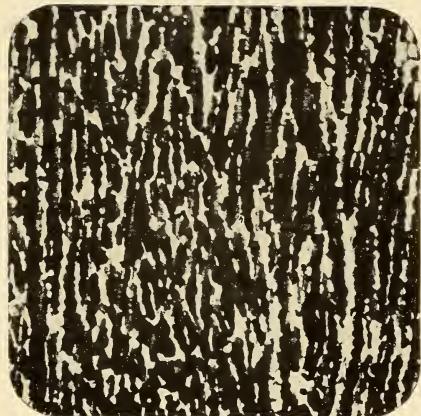
Fig. 72

Material 181 (center) × 50
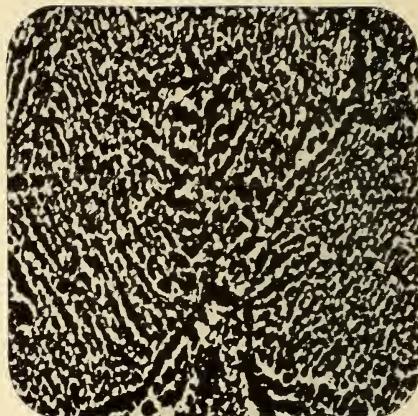
Fig. 73

Material 184 (edge) × 50
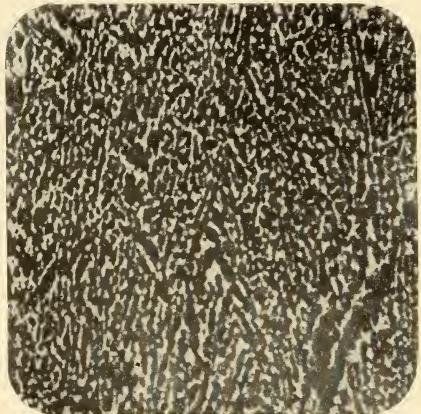
Fig. 74

Material 184 (center) × 50
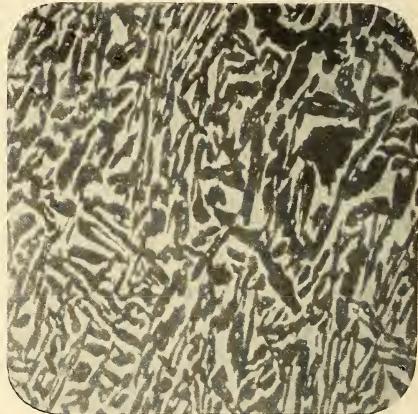
Fig. 75

Material 187 (edge) × 50
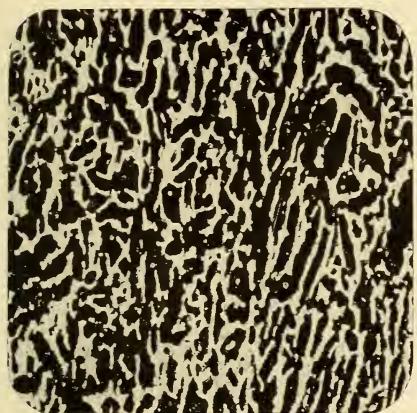
FIG. 76

Material 187 (center)   × 50
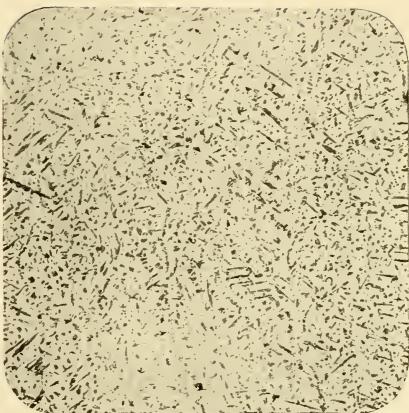
FIG. 77

Material 189 (edge)   × 25
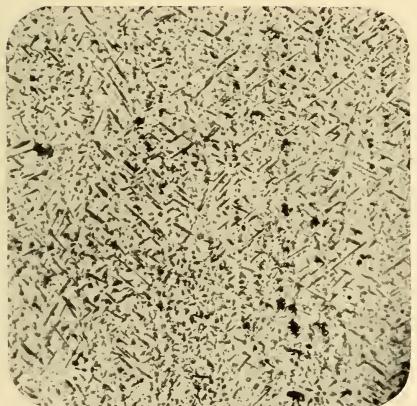
FIG. 78

Material 189 (center)   × 25
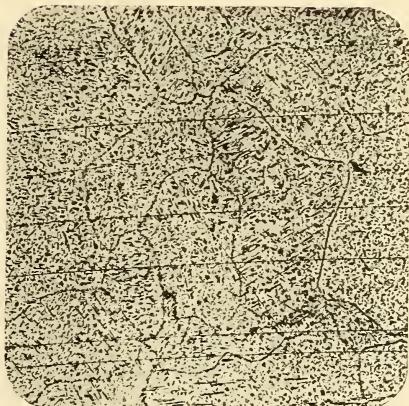
FIG. 79

Material 193 (center)   × 25
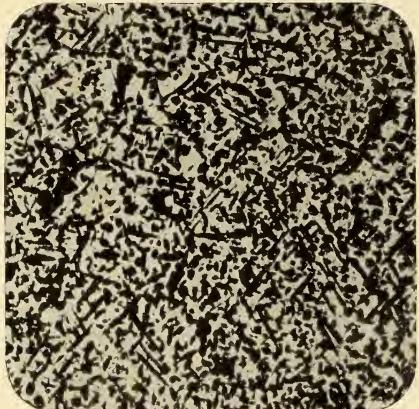
FIG. 80

Material 195 (edge) × 50
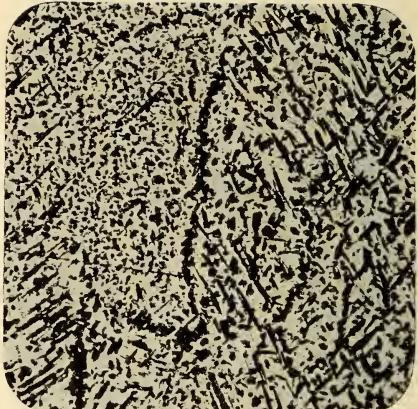
FIG. 81

Material 195 (center) × 50
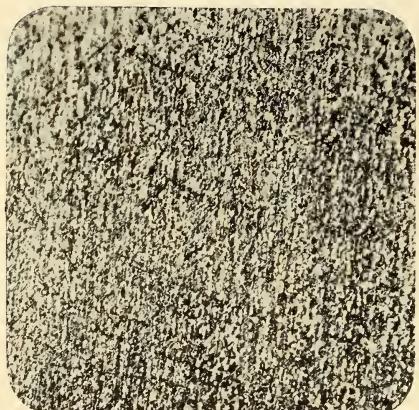
FIG. 82

Material 197 (center) × 25
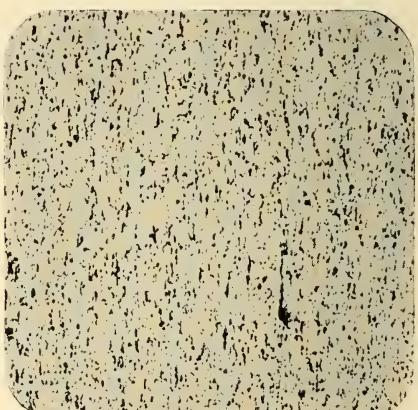
FIG. 83

Material 204 (center) × 50
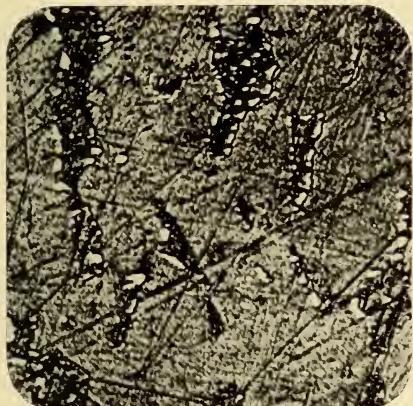
FIG. 84

Material 204 × 1000
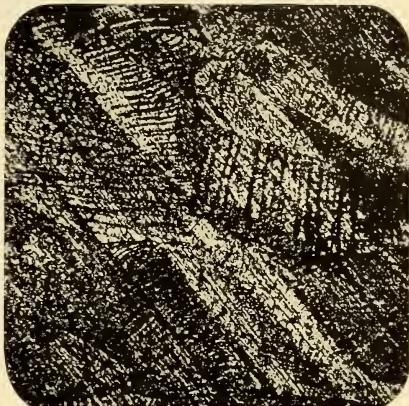
FIG. 85

Material 201 A × 400
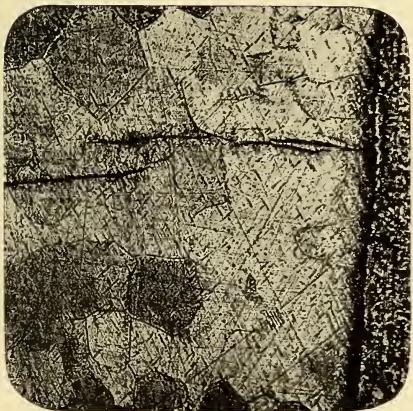
FIG. 86

Material 211 × 25
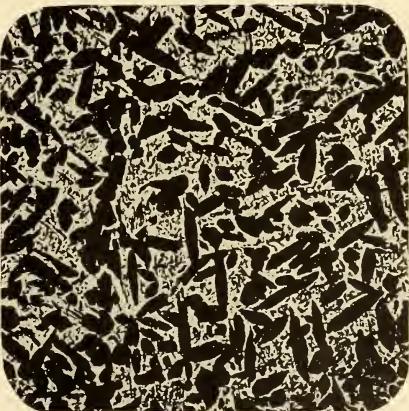
FIG. 87

Material 235 × 100

FIG. 88

Material 247 × 100
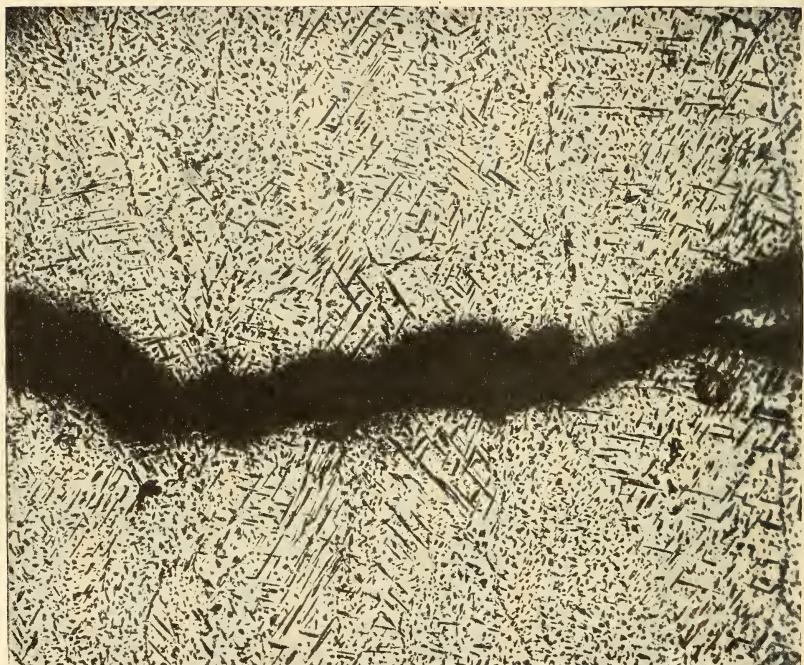
FIG. 89

Material 31 × 35
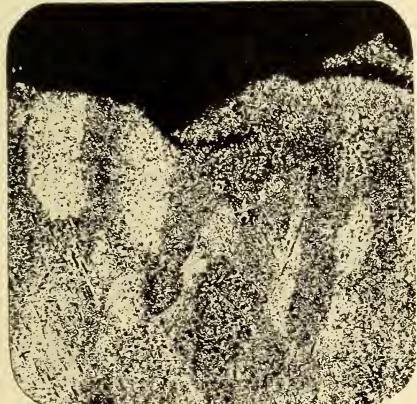
FIG. 90
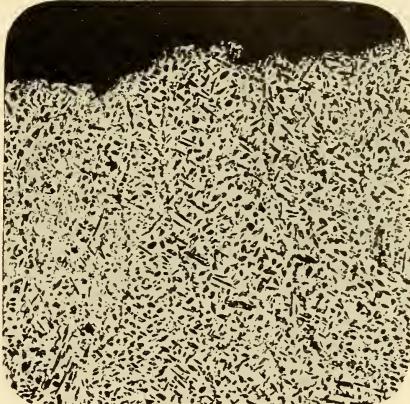
Material 34 × 20

FIG. 91

Material 38 × 35
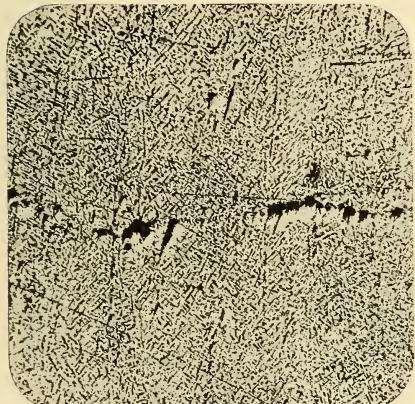
FIG. 92

Material 47 × 20
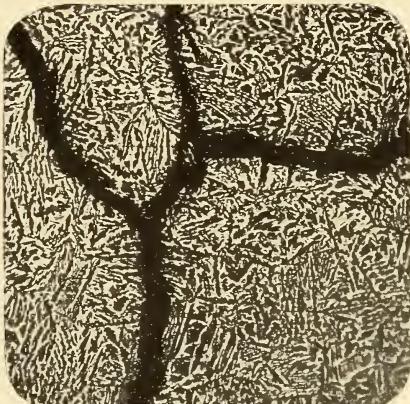
FIG. 93

Material 78 × 50

Fig. 94
Material 112 × 20
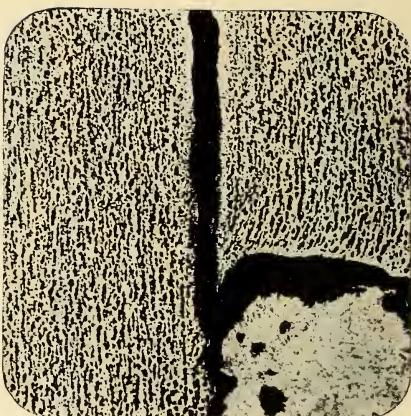
Fig. 95
Material 138 × 20

Fig. 96
Material 131 × 20
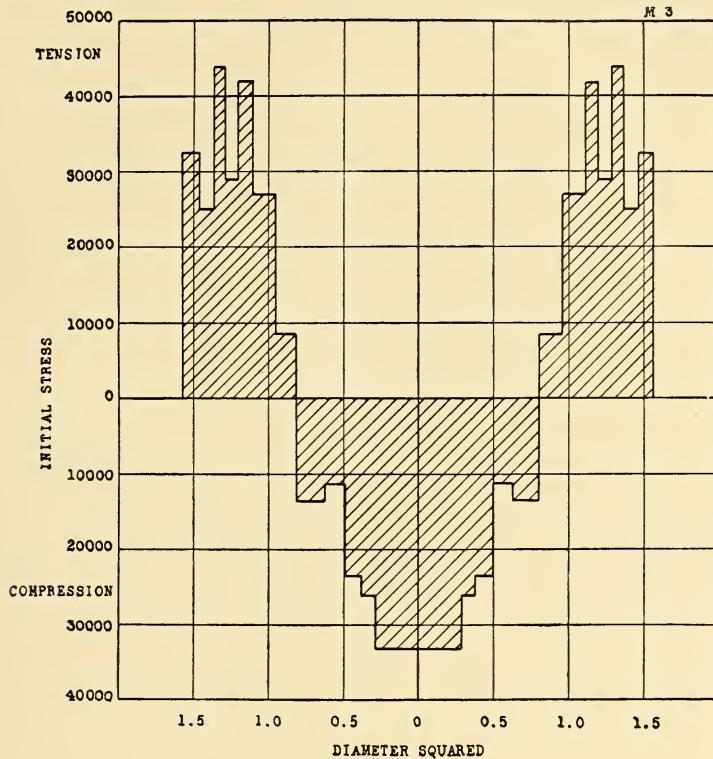
FIG. 97
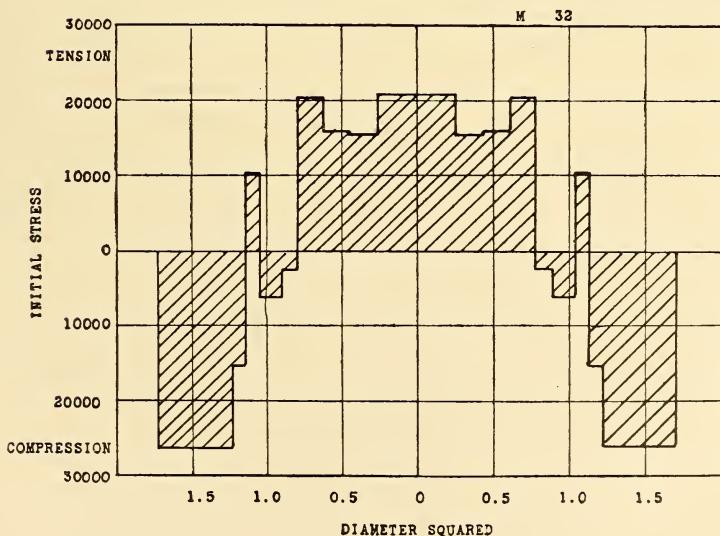
FIG. 98
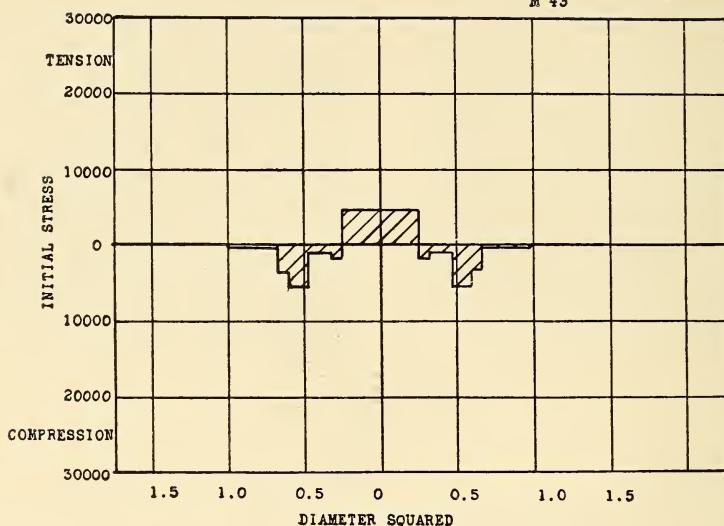
Fig. 99
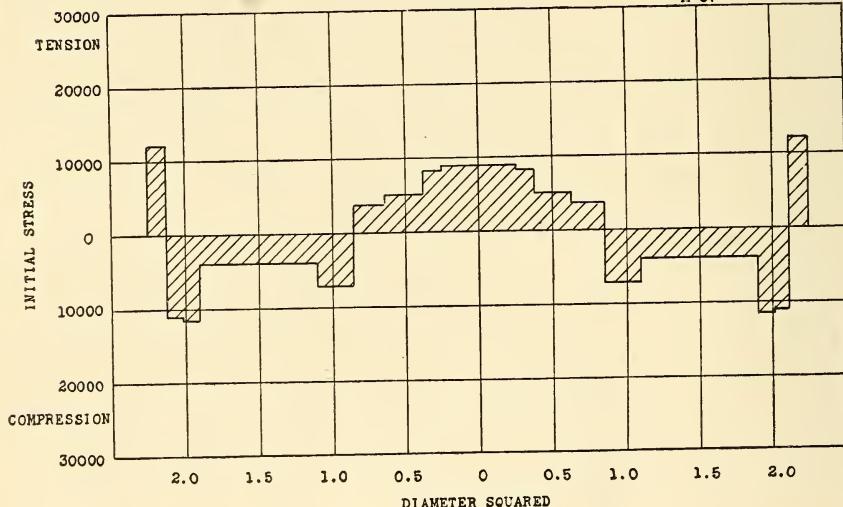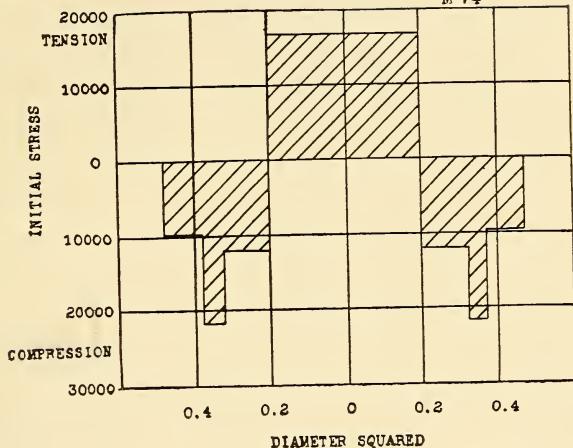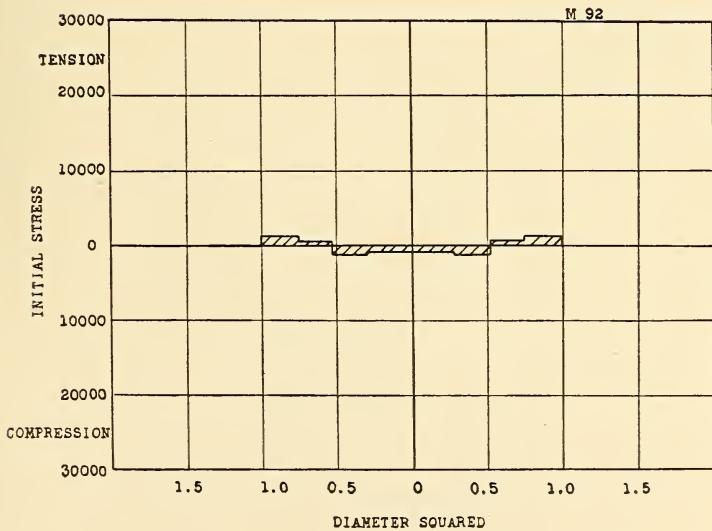
Fig. 100
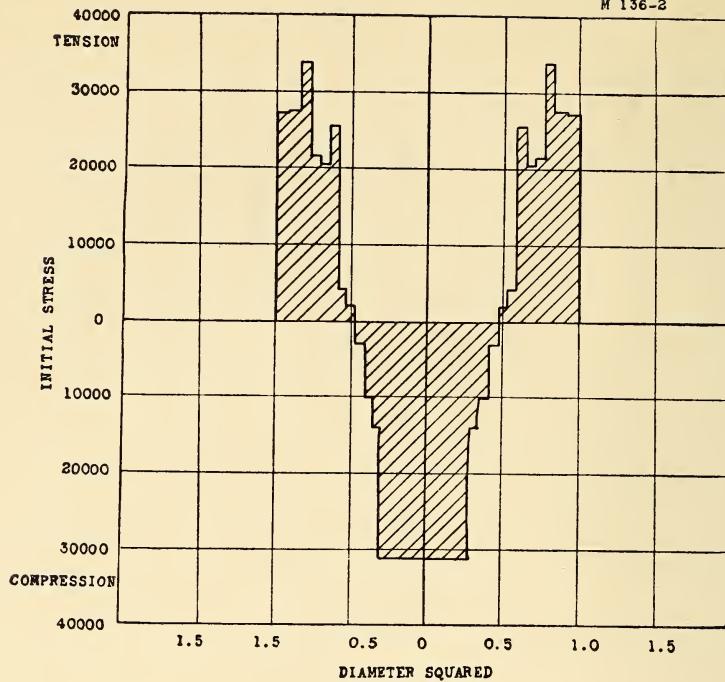
FIG. 101
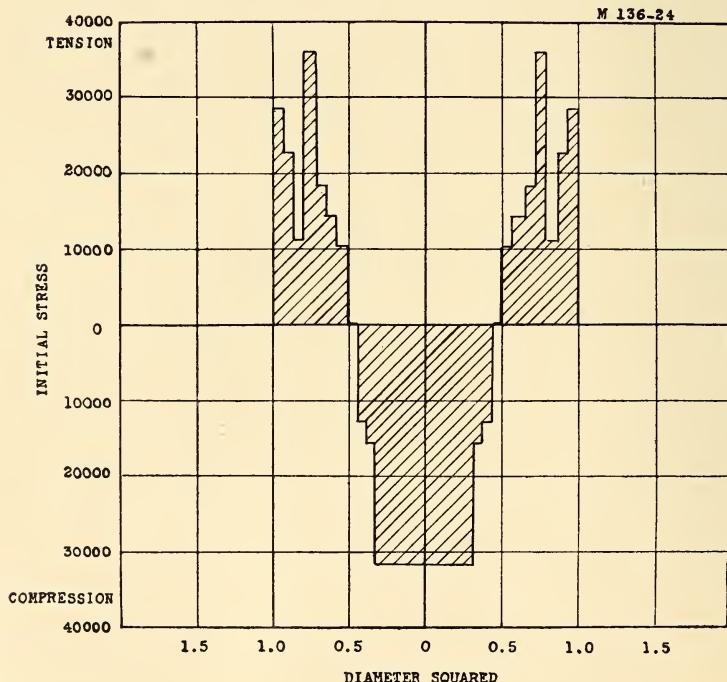
FIG. 102

Fig. 103

Fig. 104

Fig. 105

Fig. 106

FIG. 107

FIG. 108

M 214-1

Fig. 109

M 214-2
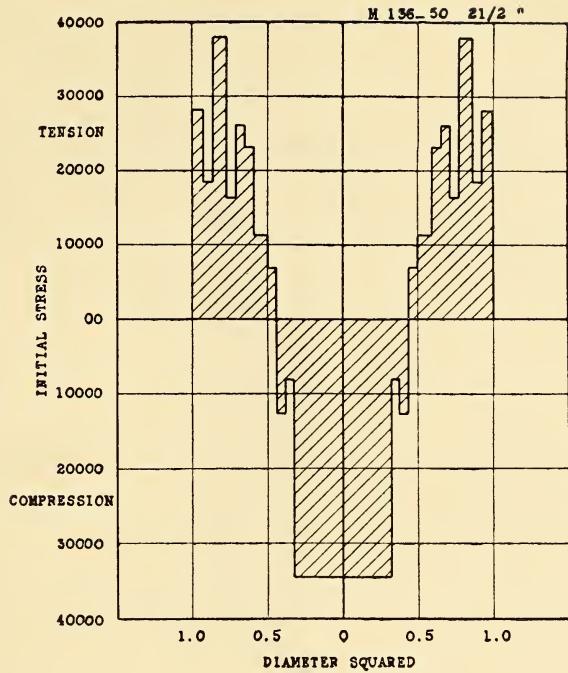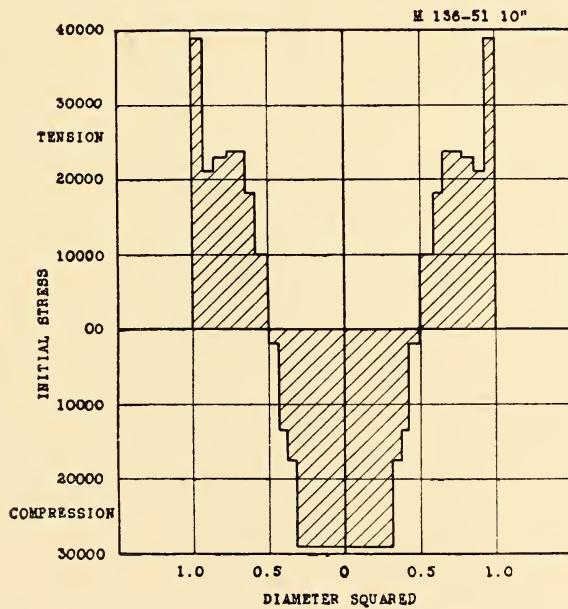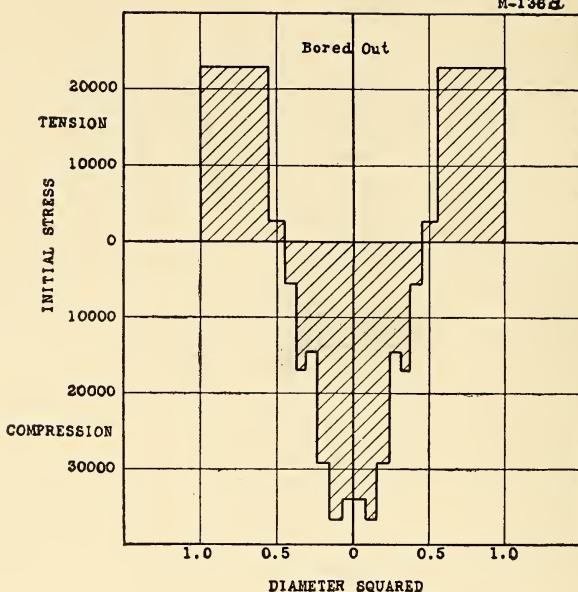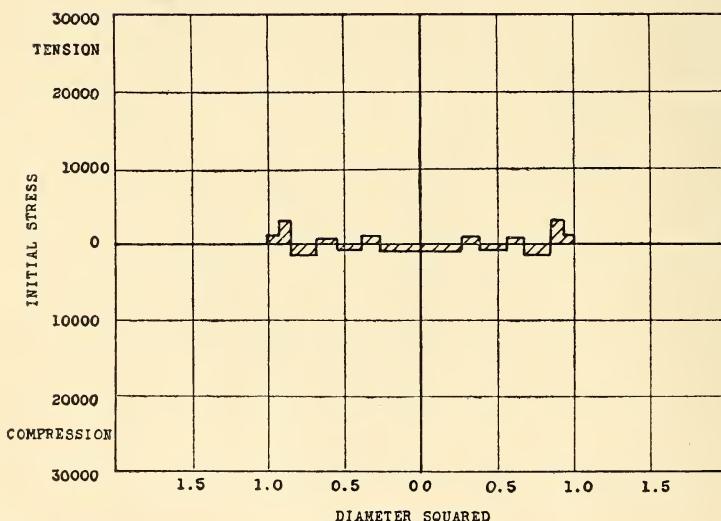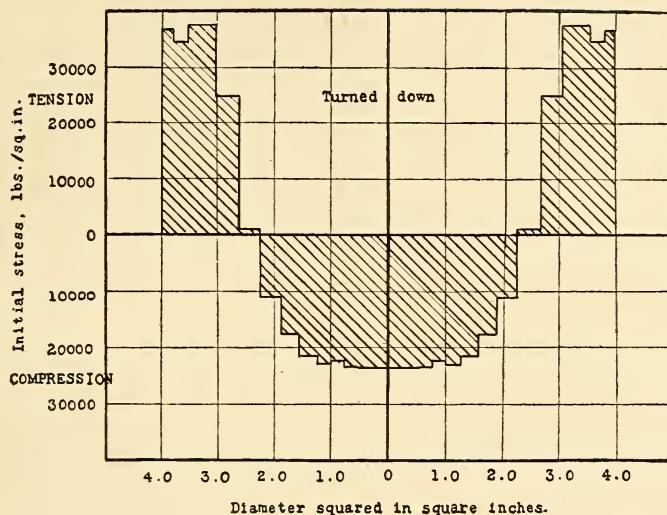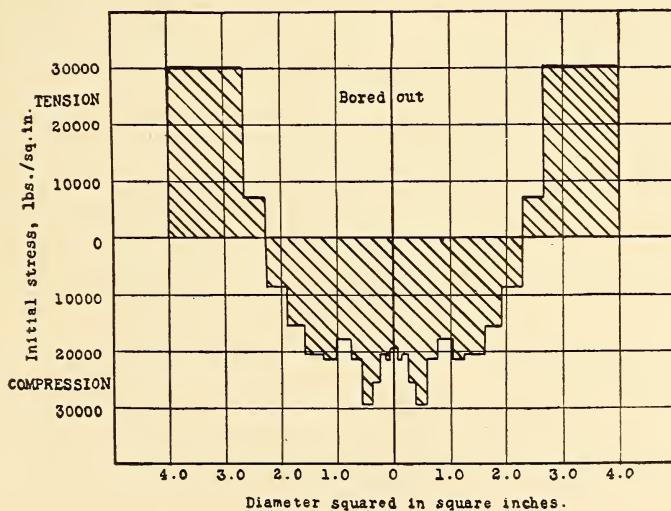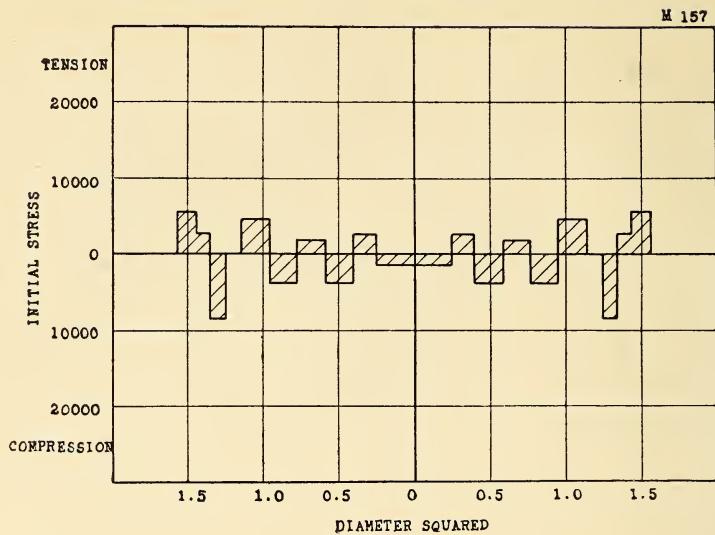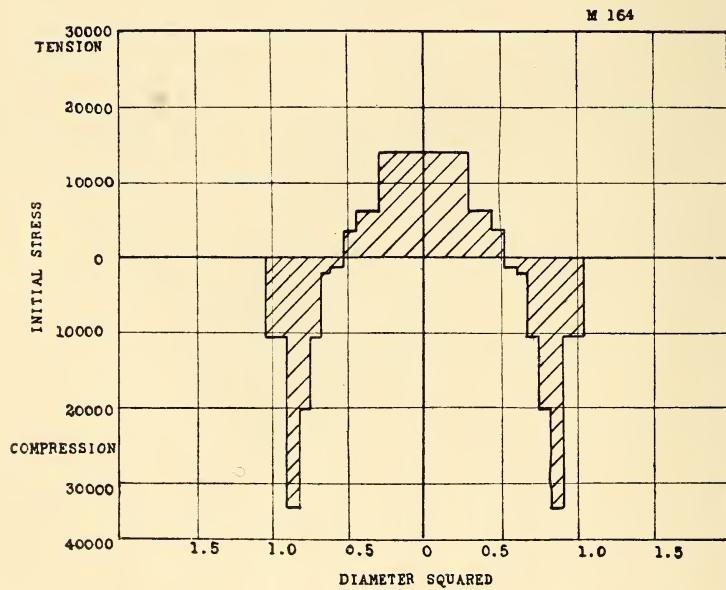
Fig. 110

FIG. III
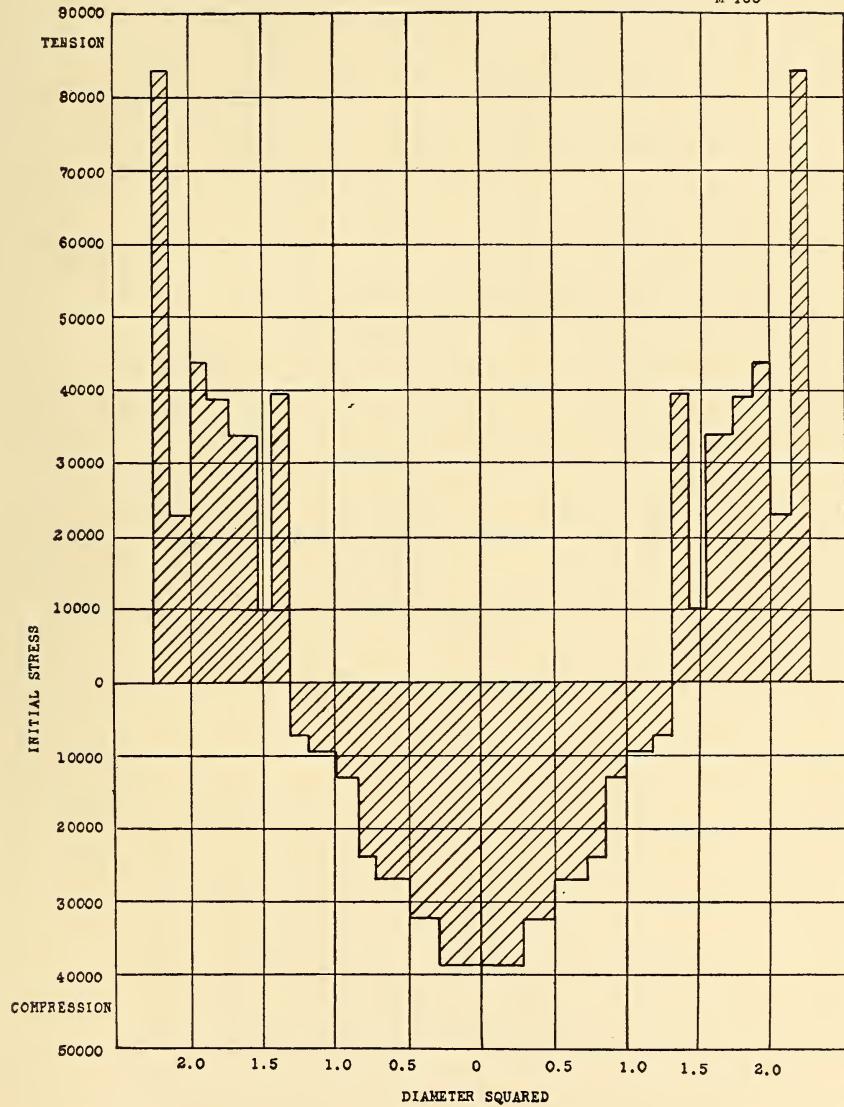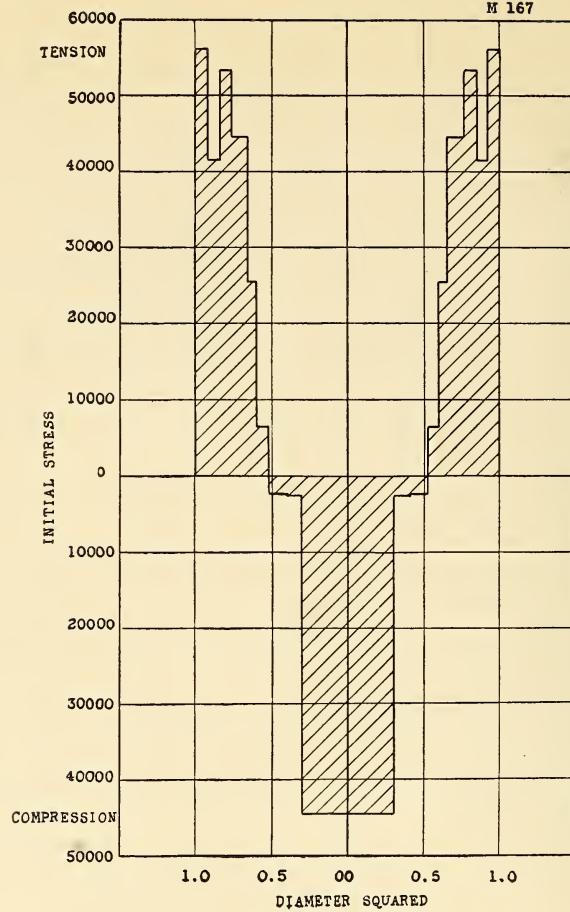
FIG. 113
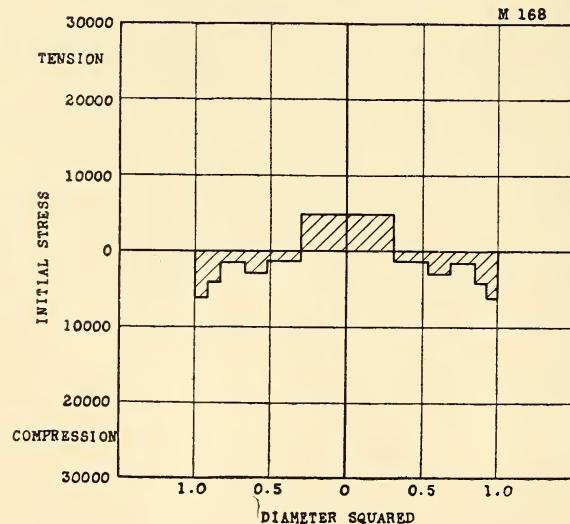
FIG. 112

Fig. 114

Fig. 115

FIG. 116

Fig. 117

Fig. 118

Fig. 119

Fig. 120